A study of the Home Heating Index and comparison with other energy-efficiency indices

Jonathan Daniel Huebner

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A STUDY OF THE HOME HEATING INDEX AND COMPARISON WITH OTHER ENERGY-EFFICIENCY INDICES

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A study of the Home Heating Index and comparison with other energy-efficiency indices

by

Jonathan Daniel Huebner

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY

Major: Physics

Approved:

Signature was redacted for privacy.

In Charge of Major Work

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For the Graduate College

Iowa State University
Ames, Iowa

1985
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTRODUCTION</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>A DESCRIPTION OF VARIOUS ENERGY-EFFICIENCY INDICES</strong></td>
<td>3</td>
</tr>
<tr>
<td>Normalized Annual Consumption</td>
<td>3</td>
</tr>
<tr>
<td>Thermal Integrity Factor</td>
<td>4</td>
</tr>
<tr>
<td>California Point System</td>
<td>5</td>
</tr>
<tr>
<td>Heating Energy Index</td>
<td>6</td>
</tr>
<tr>
<td>Passive Heating Ratio</td>
<td>6</td>
</tr>
<tr>
<td>Energy Ratio</td>
<td>7</td>
</tr>
<tr>
<td>Solar Fractions</td>
<td>8</td>
</tr>
<tr>
<td>Energy Utilization_Index</td>
<td>10</td>
</tr>
<tr>
<td>Building Energy Management Index</td>
<td>12</td>
</tr>
<tr>
<td>Computer Programs</td>
<td>13</td>
</tr>
<tr>
<td><strong>THE HOME HEATING INDEX AND RELATED QUANTITIES</strong></td>
<td>14</td>
</tr>
<tr>
<td>The Home Heating Index</td>
<td>14</td>
</tr>
<tr>
<td>Predicting the HHI Using a Computer Program</td>
<td>15</td>
</tr>
<tr>
<td>Related Quantities</td>
<td>21</td>
</tr>
<tr>
<td><strong>COMPARISON OF THE HHI WITH OTHER INDICES</strong></td>
<td>24</td>
</tr>
<tr>
<td>Home Heating Index</td>
<td>24</td>
</tr>
<tr>
<td>Thermal Integrity Factor</td>
<td>26</td>
</tr>
<tr>
<td>Solar Heating Fraction</td>
<td>27</td>
</tr>
<tr>
<td>Solar Savings Fraction</td>
<td>29</td>
</tr>
<tr>
<td>Common Solar Fraction</td>
<td>30</td>
</tr>
<tr>
<td>Passive Heating Ratio</td>
<td>31</td>
</tr>
<tr>
<td>Fractional Utilization</td>
<td>33</td>
</tr>
<tr>
<td>Other Indices</td>
<td>34</td>
</tr>
<tr>
<td>Topic</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>MEASURING THE HHI</td>
<td>35</td>
</tr>
<tr>
<td>Hodges Residence</td>
<td>36</td>
</tr>
<tr>
<td>Pyle Residence</td>
<td>38</td>
</tr>
<tr>
<td>Bremner Residence</td>
<td>40</td>
</tr>
<tr>
<td>Buildings Monitored Weekly</td>
<td>40</td>
</tr>
<tr>
<td>Other Monitored Homes</td>
<td>44</td>
</tr>
<tr>
<td>University Village Student Apartments</td>
<td>45</td>
</tr>
<tr>
<td>Schilletter Village Student Apartments</td>
<td>51</td>
</tr>
<tr>
<td>Student Apartments HHF (Winter 1983-84)</td>
<td>57</td>
</tr>
<tr>
<td>Comparison With Results From Two Random Surveys</td>
<td>64</td>
</tr>
<tr>
<td>EFFECTS OF WIND AND INSOLATION ON THE HHI</td>
<td>66</td>
</tr>
<tr>
<td>Effects of Wind on the HHI</td>
<td>66</td>
</tr>
<tr>
<td>Effects of Insolation on the HHI</td>
<td>68</td>
</tr>
<tr>
<td>PERFORMANCE OF SOLAR HOMES CALCULATED FROM DATA IN THE LITERATURE</td>
<td>72</td>
</tr>
<tr>
<td>Kelbaugh House</td>
<td>72</td>
</tr>
<tr>
<td>Balcomb House</td>
<td>73</td>
</tr>
<tr>
<td>Adjacent Conventional House and Passive Solar House</td>
<td>73</td>
</tr>
<tr>
<td>Water-Wall House</td>
<td>75</td>
</tr>
<tr>
<td>Tightly Sealed Houses</td>
<td>75</td>
</tr>
<tr>
<td>Double Envelope House</td>
<td>77</td>
</tr>
<tr>
<td>Poor Solar Homes</td>
<td>78</td>
</tr>
<tr>
<td>Six Passive Solar Homes in Denver, Colorado</td>
<td>81</td>
</tr>
<tr>
<td>CONCLUSIONS AND RECOMMENDATIONS</td>
<td>84</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>87</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>90</td>
</tr>
<tr>
<td>APPENDIX: HHI COMPUTER PROGRAM</td>
<td>91</td>
</tr>
</tbody>
</table>
INTRODUCTION

With limited energy resources, it is important to know the efficiencies of various energy-consuming devices, and to be able to compare the efficiencies of similar devices. For example, a commonly used measure of efficiency is the miles per gallon rating of a car. There are a wide variety of cars, and the mpg rating of any single car can be easily measured and compared with that of any other car.

A home, for many people, requires more energy than their cars, yet occupants have had no scale to easily and accurately measure their home's efficiency or to compare it with other homes. The HHI was developed for these reasons, and it is the only known index which satisfies these requirements.

A literature survey was carried out to determine which indices were currently in use and their characteristics. Quite a few indices were discovered, but they all have serious flaws and were found to be unsatisfactory; some are defined for limited climate regions, some are too complicated and difficult to measure easily, and others are inconsistent and vary from month to month.

The HHI has been carefully defined to avoid the problems encountered with the other indices. Additionally, a number of related quantities has been defined to provide greater flexibility in cases when the HHI is not appropriate, as when the efficiency of the energy distribution system is considered. To make things easier for architects
and construction companies, a computer program has been written to predict the HHI of a building using information from construction drawings.

Once the computer program was written, it was necessary to calculate the HHI, as well as each of the other indices, for an example house to make sure the HHI really was superior. A careful comparison did in fact reveal the stronger merits of the HHI as expected.

Although the HHI performed well theoretically, it was still necessary to take measurements to insure that it worked well in reality. A number of houses and apartments were monitored during the winter of 1984-85 to determine the shortest time period required to measure the HHI with reasonable accuracy. Variations in the energy-efficiencies of apartment units within the same building were studied as well. Theoretical HHI values of some homes were compared to the measured values, and a comparison was made with results of two random surveys of homes in central Iowa. Also, the HHI of different types of houses were measured under various weather conditions, and a study was done to determine the effects of wind speed and insolation on the HHI.

Finally, a survey of passive solar homes across the country was undertaken to see if their HHI values indicated that they really were energy-efficient. All data for these homes were gathered from published articles. A number of different types of passive solar homes were studied, including some famous solar homes, and almost all of them were found to be energy-efficient.
A DESCRIPTION OF VARIOUS ENERGY-EFFICIENCY INDICES

There are many different indices which are claimed to accurately represent the energy efficiency of buildings. Many researchers simply rate a building by the total purchased energy, in Btu, per year. Others use the building heat loss coefficient divided by the floor area or the total purchased energy per square foot per degree-day (65°F base). However, some indices, such as the Normalized Annual Consumption, are more sophisticated.

Normalized Annual Consumption

Fels and Goldberg (1984, p. 439) have defined for gas-heated homes a weather-adjusted conservation index, $\Gamma$, called the Normalized Annual Consumption (NAC). $\Gamma$ represents the natural gas consumption per household for an average year, and is a function of three parameters: $\alpha$, $\beta$, and $T$.

$\alpha$ represents the base level fuel usage (for kitchen ranges, water heaters, or other gas-heating appliances) and is independent of the outside temperature. $\beta$ is the fuel consumed per degree drop in outside temperature. $T$ is the cutoff temperature above which no heating fuel is needed. These three parameters are found by a regression analysis of the following equation:

$$\Gamma_i = \alpha + \beta WH_i(T)$$

where $\Gamma_i$ is the measured average daily consumption for month $i$, and
WH_i(τ) is a weighted average of the heating degree days from base temperature τ for month i. Gamma is then calculated by

\[ \Gamma = 365 \alpha + \beta H_0(\tau) \]

where \( H_0(\tau) \) is the average annual heating degree-days to base τ.

Fels and Goldberg determined \( \Gamma \) using data from 900,000 gas heated households in New Jersey, and found that it decreased 26% from 1973 to 1982. 48% of this decrease was attributed to a drop in τ of two degrees Celsius. Lower values for α and β each contributed 26% to the total decrease.

Although the uncertainty in the changes in α, β, and τ was 30% to 40%, the decrease in τ was interpreted to result from lowered thermostat settings, the change in β to structural retrofits or furnace efficiency improvements, and the drop in α to decreased gas appliance usage or increased appliance efficiency.

Thermal Integrity Factor

An index that has been used for a number of years is the Thermal Integrity Factor (TIF) (Williams et al., 1983, p. 269). The TIF is defined as the annual thermal contribution of a house's heating system per unit floor area per degree day, and is calculated as follows:

1) Determine the Btu delivered to the interior of a house by the heating system for an entire year.

2) Divide by the total number of Fahrenheit degree days, based on 65°F, for the entire heating season.

3) Divide the result of step 2) by the floor area (in square feet).
California Point System

In the California Point System (Steel, 1983, p. 567), the state of California is divided up into 16 climate regions. For each region, a list of 20 energy savings categories is compiled with hundreds of options. The January 1982 version of the point system rates the following categories: slab perimeter insulation; raised floor insulation; ceiling insulation; wall insulation; single, double, or triple glazed windows of varying area, orientation and shading; single, double and triple glazed skylights with varying area and shading; south window roof overhangs; movable insulation; infiltration barriers with an air-to-air heat exchanger; thermal mass; and heating and cooling equipment efficiency including optional solar space and water heating.

Positive points are assigned to devices which save energy beyond a standard level, and negative points to devices which are below that level. Each positive point corresponds to an annual source energy savings, compared to the standard home, of 500 Btu per square foot of floor area. A home is rated by adding up all the points, and the point total must be greater than or equal to zero for a new home to meet the building energy code requirements.

The accuracy of the point system was tested by analyzing the utility bills from 99 homes and comparing the average annual source energy for space heating and cooling with the average point system energy calculations. The two averages were found to be equal, although some individual identical homes had up to a factor of two difference in their energy consumption.
Heating Energy Index

Don Schramm (1980, p. 384), from the University of Wisconsin, uses a Heating Energy Index (HEI) to measure the energy efficiency of his home. It is calculated as follows:

1) Determine the total energy used for heating during an entire winter.
2) Divide the total energy use by the total heated floor area.
3) Divide the result of step 2) by the total degree days for the winter. The final index has units of Btu/sq.ft./dd.

It is not clear if the efficiency of the heater is considered, if only the heat delivered to the interior of the house is measured, or if the total metered fuel is counted. Also, the base temperature for calculating the degree days was not mentioned in Schramm's article.

Passive Heating Ratio

The National Bureau of Standards (McKinstry et al., 1980, p. 346) considers the Passive Heating Ratio (PHR) to be a primary performance factor for buildings. The PHR is that fraction of a building's heat load which is attributed to passive solar heating, and is found by the following set of equations:

1) $Q_{loss} = L(T_i - T_0)$

where $Q_{loss}$ = gross heat loss from the living zone due to air infiltration and heat transmission through the envelope. (The living zone is defined as the spaces with temperatures always within $5^\circ$ of
conditioned space temperatures.

L = overall loss coefficient in the absence of sunlight

T_i = living zone temperature

T_o = outside air temperature

2) \( Q_{pash} = Q_{loss} - Q_{auxh} - Q_{int} \)

where \( Q_{pash} \) = passive solar heating delivered to the living zone

\( Q_{auxh} \) = auxiliary heating delivered to the living zone

\( Q_{int} \) = internal heat gains delivered to the living zone

3) PHR = \( Q_{pash} / Q_{loss} \)

Other primary performance factors used by the National Bureau of Standards are the fuel savings due to the passive system, total purchased space heating and cooling energy, and the thermal storage element efficiency.

Energy Ratio

Bailey (1982, p. 599) has defined an Energy Ratio (ER) to determine the amount of energy returned for each unit of energy required to construct the solar energy system of a house.

\[ ER = \frac{\text{usable delivered energy}}{\text{(direct and indirect energy used to construct and operate the energy system)}} \]

Indirect energy required to operate an electric heat pump system, for example, includes the energy to mine the coal for a power plant, plus the energy required to ship the coal to the plant, and also the power consumed by the plant and transmission losses in the distribution of electricity to the heat pump.
Solar Fractions

There are many different indices, called Solar Fractions (SF), which are based on the solar heat input into a home. Most authors use one of two general methods to calculate a SF.

1. \[ SF = \frac{Q_{\text{saved}}}{Q_{\text{reference load}}} \] (additive method)
2. \[ SF = 1 - \frac{Q_{\text{auxiliary}}}{Q_{\text{reference load}}} \] (subtractive method)

\(Q_{\text{saved}}\), \(Q_{\text{reference load}}\), and \(Q_{\text{auxiliary}}\) are all determined differently by almost every author. Palmiter and Hamilton (1979, p. 318) have calculated six different Solar Fractions for a direct gain building and found a five-to-one ratio in the amount of heat saved between the two most extreme estimates.

An article by Abrams (1981, p. 343) mentions several indices in use: Solar Heating Fraction (SHF), Solar Savings Fraction (SSF), and Relative Solar Savings Fraction (RSSF).

\[ \text{SHF} = \frac{\text{(Net solar contribution)}}{\text{(Actual net load)}} \]
\[ \text{SSF} = \frac{\text{(Solar savings)}}{\text{(Reference net load)}} \]

The actual net load is the heating load of a similar building with the solar aperture replaced by an adiabatic wall that neither loses nor gains heat. The reference net load is calculated similarly, except that the building is assumed to be held at a constant reference temperature.

\[ \text{RSSF} = \frac{Q_{\text{aux}} - Q'_{\text{aux}}}{Q_{\text{aux}}} \]

where \(Q_{\text{aux}}\) = auxiliary heating load by a building with evenly spaced windows around its perimeter.

\(Q'_{\text{aux}}\) = auxiliary heating load by a sun-tempered building with most of its windows facing south.
Abrams then defines the Common Solar Fraction (CSF) to be:

\[
CSF = \frac{\text{Gross solar contribution}}{\text{Gross load}}
\]

The CSF may be calculated using the SSF by the following relation:

\[
CSF = 1 - \frac{(1-SSF)}{1+24U_p/LCR}
\]

where \( LCR \) = load collector ratio in Btu/DD

\( U_p \) = steady-state U-value of passive element in

\[
\text{Btu/(hr)(deg F)(sq. ft.)}
\]

Balcomb (1983, p. 6) defines SSF as:

\[
SSF = 1 - \frac{\text{auxiliary heat}}{\text{net reference load}}
\]

where the net reference load is the building load coefficient (BLC) multiplied by the number of degree days (DD) and is based on a constant indoor reference temperature, normally 65°F. The auxiliary heat requirement can be easily calculated using SSF:

\[
\text{auxiliary heat} = (1 - SSF) \times \text{BLC} \times \text{DD}
\]

Note that a building with a high SSF would have low heating requirements, but would be expensive to build. On the other hand, a building with a low SSF would have high heating requirements, but would be cheaper to build. An optimum SSF is achieved when a satisfactory balance is reached between the two costs. The recommended SSF varies from 0.1 in northern Minnesota to 0.8 in the southwestern United States. Balcomb’s Solar Load Ratio and Solar Heating Fraction are discussed later.

Kohler, Michal, Sullivan, and Lewis (1979, p. 415) use Fractional Utilization (FU) as an indicator of an efficient solar design:

\[
FU = \frac{\text{load - auxiliary}}{\text{incident solar}}
\]
The load is the product of the overall heat transfer coefficient of the building and the difference between inside and outside temperatures. Auxiliary is the space heating energy consumption per day, and incident solar is the total incident solar radiation for one day.

Energy Utilization Index

Monts and Blissett (1982, p. 861) have published an article on the Energy Utilization Index (EUI). The EUI is a function of climate; heating, ventilation, and air conditioning system design; indoor design temperature, occupancy patterns, building envelope thermal integrity, and building use. It expresses the total energy (electricity, natural gas, fuel oil, propane, purchased steam, purchased chilled water, etc.) used by a building in a given period in terms of Btu per gross conditioned squarefoot. A linear regression analysis of the following equation is performed to find the EUI:

\[
EUI = B_0 + B_1 \times HDD + B_2 \times CDD + B_3 \times DAYOCP + B_4 \times YRRND +
\]

\[
B_5 \times DAYLONG + B_6 \times DXWU + B_7 \times EC + B_8 \times PAFC + B_9 \times SDSZ +
\]

\[
B_{10} \times TR + B_{11} \times DD + B_{12} \times MZ + B_{13} \times SSP + B_{14} \times UC0 + B_{15} \times UD + B_{16} \times USP
\]

where \(B_0\) = zero-intercept

\(B_1\) thru \(B_{16}\) = regression coefficients

HDD = heating degree days

CDD = cooling degree days

DAYOCP = number of day occupants Monday through Friday
YRRND = one if the building operates all year long and zero if it does not
DAYLONG = one if the building operates 24 hours per day and zero if it does not
(The remaining variables similarly take on values of either zero or one.)
DXWU = Direct Expansion window units variable
EC = Evaporative Coolers variable
PAFC = Primary-Air-Fan-Coil variable
SDSZ = Single-Duct-Single-Zone variable
TR = Terminal-Reheat variable
DD = Dual-Duct variable
MZ = Multizone variable
SSP = School Special Purpose building variable
UCO = University Classroom and Office variable
UD = University Dormitory Variable
USP = University Special Purpose variable

Data from 342 Texas school and university buildings were used to find the regression coefficients, yielding the following result:

\[ EUI = -558391 + 122.52*HDD + 179.36*CDD - 13.71*DAYOCP - 1359*YRRND \\
+ 76469*DAYLONG + 40564*DXWU - 27581*EC + 124005*PAFC \\
- 11400*SDSZ + 203193*TR + 36208*DD + 78641*MZ + 93232*SSP \\
+ 99805*UCO + 65722*UD + 286066*USP \]

Only 42% of the variation in the EUI was accounted for, as the correlation coefficient was 0.42. Also, Monts and Blissett were unable
Building Energy Management Index

The Building Energy Management Index (BEMI) (Zeimet, 1984, p.349) is calculated as follows:

1) Determine the average energy, in Btu, consumed per day for one month.

2) Calculate the average number of man-hours of occupancy per day for one month.

3) Find the total square footage of the building.

4) Determine the "relative temperature" by adding 40°F to the average monthly temperature.

5) The Building Energy Characteristic (BEC) is step 1) divided by the product of step 3) and step 4).

6) The Building Function Characteristic (BFC) is step 2) divided by the product of step 3) and step 4).

7) Calculate the BEC and BFC for the remaining 11 months of the year and plot BEC vs. BFC on a graph.

8) The BEMI is the least-squares fit line through the points. Lower energy consumption would decrease the magnitude of the BEMI's slope, while the y-intercept would remain the same or decrease.
Computer Programs

Computer programs have been used extensively to model the energy requirements of buildings. The complexity of these programs vary from simple programmable calculator simulations to extremely sophisticated computer models which incorporate such details as wall colors and the location of furniture in a room. Of course, it takes much longer to input all the information into the more complicated models, and also more time for the computer to do the calculations.

Gadgil, Goldstein, Kammerud, and Mass (1979, p. 187) from Lawrence Berkeley Laboratory have compared four popular computer programs which calculate both heating and cooling loads: DOE-1/DOE-2, NBSLD, BLAST-2, and TWOZONE. The programs simulate internal heat storage and internal radiative and convective heat transfers for user-defined building envelopes and glazing systems. Each of the four programs assumes room air is homogeneous and of uniform temperature. They also consider that the energy absorbed from sunlight is distributed uniformly over the entire floor.

It was found that the programs were in good agreement for houses with small solar gains, compared to the total heating load, but diverged from one another for houses in which solar effects were large. The disagreement was reduced to less than 6% when solar gain was eliminated, even for sunny weather. Discrepancies were attributed to different models of internal heat transfer used by the programs.
The Home Heating Index

The Home Heating Index (HHI) has been developed by the Iowa State University Extension Service (Hodges, 1984b, p. 172) to express the energy efficiency of a home by a single number. Various components of a home have measures which represent their efficiency, such as the Annual Fuel Utilization Efficiency for natural gas furnaces or the Energy Efficiency Ratio for air conditioners. The need for an index that represents the efficiency of an entire house and that remains constant, independent of the living patterns of the occupants, from month to month during the winter, motivated the development of the HHI.

It is possible to calculate the HHI using utility bill information or estimate it from construction drawings. In either case, the HHI may be found as follows:

1. Determine the total amount of energy delivered to the interior of the home from December 1 through February 28 to maintain it at an average temperature $T_i$. If utility bills are used, then efficiencies of gas furnaces, stoves, hot water heaters, etc. must be considered as only the heat that enters the home should be counted.

2. Divide by the total number of degree-days to base temperature $T_i$ over the same time period. This result is the Home Heating Requirement (HHR).

3. Divide by the interior area of the home. This result is the
HHI, with units of Btu/°-day-ft^{2}. The HHI may be calculated in the mks system of units using 1 Btu/°-day-ft^{2} = 0.237 W/°C-m^{2} as a conversion factor. Outside walls are not included nor are crawl spaces or other areas which are not normally accessible. Additionally, the floor area of any unheated rooms kept below 50°F is not counted. The area used in calculating the HHI must be the same area for which the average temperature $T_1$ is determined.

Determining the total energy delivered to the interior is fairly easy for most homes if the only sources of energy are provided by utilities. There are uncertainties as to furnace efficiencies and heat lost up the flue. It is also difficult to know the heat lost down the drain with water or the heat contribution from human metabolism. Fortunately, these last two items are opposite in sign and approximately equal in magnitude, and are therefore not considered.

Other sources of energy excluded are the solar energy collected by a passive solar system or a roof-top active solar collector. Also, solar electricity from a photovoltaic array mounted on the house is not included. Only energy sources brought into the home from the outside are counted and not those collected by the home itself.

Predicting the HHI Using a Computer Program

Calculating the total heat energy input to maintain the house at an overall average temperature throughout the winter from construction drawings is more involved than using utility bill information. A computer program, written in BASIC to run on an IBM PC, listed in the
appendix, will calculate the HHI of a building given various inputs about the building and weather conditions.

The first step the computer program does is to calculate the building heat loss coefficient. This calculation is performed by summing the heat loss of each component of the building, such as walls, ceiling, windows, etc. and adding the heat loss due to air infiltration. For example, the heat loss of a wall, in Btu per degree-day, would be its area in square feet multiplied by 24 hours and then divided by its R-value. For underground walls, only the first three feet below ground level are considered in finding an average heat loss for the total wall. Air infiltration is generally the largest single source of heat loss and is found by multiplying the heat capacity of air (0.018 in the British system of units) by the air changes per hour by the volume of the house by 24 hours.

The next step is to calculate the gross heat loss for each of the three winter months: December, January, and February. This result is obtained by multiplying the building heat loss coefficient found in the first step by the monthly degree-days (generally to base 65°F).

One of the more complicated steps is finding the solar heat input; it is estimated as follows:

1. The solar declination, $D$, is the angle from the celestial equator to the sun's position; it varies from -23.45° at the December solstice to 23.45° at the June solstice. It is given by the following equation:

$$\sin D = 0.3979 \sin(360°(284 + N)/365)$$
where $N$ is the day of the year.

2. $H_s$ is the sunset hour angle and is measured westward from due south (solar noon), $15^\circ$ each hour. For example, sunset at 4:00 PM solar time corresponds to $H_s = 60^\circ$. The equation for $H_s$ given the solar declination, $D$, on a particular day is

$$\cos H_s = -\tan D \tan L$$

where $L$ is the latitude (Ames = $42.0^\circ$).

3. $I_Q$ is the total daily solar radiation on a horizontal surface above the earth’s atmosphere and is given by:

$$I_Q = \frac{(24\text{hours}/\pi)I_{sc}(1 + 0.033\cos(360^\circ N/365))}{(\cos L \cos D \sin H_s + (2\pi H_s/360)(\sin L \sin D))}$$

where $I_{sc}$ is the solar constant which is the solar radiation on a plane perpendicular to the sun’s rays above Earth’s atmosphere. In the British system of units $I_{sc}$ is 429 Btu/ft$^2$-hour, and in other units it is 1353 W/m$^2$ = 4871 kJ/m$^2$-hour = 1.94 langley/minute = 116.4 langley/hour.

4. $R_b$ is the ratio of daily beam radiation on a tilted surface to that on a horizontal surface and is given by:

$$R_b = (\cos s \cos L \sin L)((H_{ss} - H_{sr})\pi/180)$$

$$- (\sin D \cos L \sin s \cos G)((H_{ss} - H_{sr})\pi/180)$$

$$+ (\cos D \cos L \cos s)(\sin H_{ss} - \sin H_{sr})$$

$$+ (\cos D \cos G \sin L \sin s)(\sin H_{ss} - \sin H_{sr})$$

$$- (\cos D \sin s \sin G)(\cos H_{ss} - \cos H_{sr})/2$$

$$2(\cos L \cos D \sin H_s + (\pi H_s/180)\sin L \sin D)$$

where $G$ is the azimuthal angle of the surface (due south = $0^\circ$),
H_{sr} is the sunrise hour angle on the surface,
H_{ss} is the sunset hour angle on the surface,
s is the tilt angle of the surface, measured from the horizontal.

For G>0:
\[ H_{sr} = -\min(H_s, \arccos((AB + (A^2 - B^2 + 1)^{1/2})/(A^2 + 1))) \]
\[ H_{ss} = \min(H_s, \arccos((AB - (A^2 - B^2 + 1)^{1/2})/(A^2 + 1))) \]

For G<0:
\[ H_{sr} = -\min(H_s, \arccos((AB - (A^2 - B^2 + 1)^{1/2})/(A^2 + 1))) \]
\[ H_{ss} = \min(H_s, \arccos((AB + (A^2 - B^2 + 1)^{1/2})/(A^2 + 1))) \]

where
\[ A = (\cos L)/(\sin G \tan s) + (\sin L)/(\tan G) \]
\[ B = (\tan L \cos L)/(\tan G) - (\sin L)/(\sin G \tan s) \]

5. R is the ratio of insolation (incident solar radiation) on a tilted surface to that on a horizontal surface. It can be modeled by the equation:
\[ R = (1 - (I_D/I))R_B + (I_D/I)(1 + \cos s)/2 + (1 - \cos s)r/2 \]

where \( I_D \) is the daily diffuse solar radiation on a tilted surface.
\( r \) is the ground reflectance (\( r = 0.7 \) when there is one inch or more of snow on the ground and \( 0.2 \) when there is no snow).
\( I \) is the total daily solar radiation on a horizontal surface (a measured quantity).
\( I_D \) can be approximated (Liu and Jordan, 1960, p. 1) by the equation:
\[ I_D/I = 1.39 - 4.03K_T + 5.53(K_T)^2 - 3.11(K_T)^3 \]
where $K_T$ is the clearness index:

$$K_T = \frac{I}{I_0}$$

6. $I_T$ is the total radiation on a surface of arbitrary tilt and orientation. $I_T$ is then

$$I_T = RI = RK_T I_0$$

7. Finally, the monthly solar heat input for one window is found by multiplying $I_T$ by the clear area of the window, by the number of days in the month, and by the average transmittance of the glass. This process must be repeated for each window.

Balcomb’s Solar Load Ratio (SLR) method (Balcomb et al., 1982, p. 67) is used to estimate the auxiliary heat input. SLR is the solar heat input divided by the gross heat loss. The Solar Heating Fraction (SHF) is a function of the SLR and is given by:

when $\text{SLR}/(f + G/BHLC) > R$

$$\text{SHF} = 1 - f(1 - B + C \exp(-D(\text{SLR})/(1 - f + G/BHLC)))*(1 + GA_p/BHLC))$$

when $\text{SLR}/(f + G/BHLC) < R$

$$\text{SHF} = 1 - f((1 - A(\text{SLR})/(f + G/BHLC))(1 + GA_p/BHLC))$$

where $A$, $B$, $C$, $D$, $G$, and $R$ are listed in Table 1 (Balcomb et al., 1982, p. 67) for various types of direct gain systems, A1 through C3. The direct gain systems are described in Table 2 (Balcomb et al., 1982, p. 67). $A_p$ is the area of the solar aperture multiplied by the sine of the tilt angle as measured from the horizontal.
Table 1. Coefficients for various direct gain systems

<table>
<thead>
<tr>
<th>System</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>R</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.5650</td>
<td>1.0090</td>
<td>1.0440</td>
<td>0.7175</td>
<td>0.3931</td>
<td>9.36</td>
</tr>
<tr>
<td>A2</td>
<td>0.5906</td>
<td>1.0060</td>
<td>1.0650</td>
<td>0.8099</td>
<td>0.4681</td>
<td>5.28</td>
</tr>
<tr>
<td>A3</td>
<td>0.5442</td>
<td>0.9715</td>
<td>1.1300</td>
<td>0.9273</td>
<td>0.7086</td>
<td>2.64</td>
</tr>
<tr>
<td>B1</td>
<td>0.5739</td>
<td>0.9948</td>
<td>1.2510</td>
<td>1.0610</td>
<td>0.7905</td>
<td>9.60</td>
</tr>
<tr>
<td>B2</td>
<td>0.6180</td>
<td>1.0000</td>
<td>1.2760</td>
<td>1.1560</td>
<td>0.7528</td>
<td>5.52</td>
</tr>
<tr>
<td>B3</td>
<td>0.5601</td>
<td>0.9839</td>
<td>1.3520</td>
<td>1.1510</td>
<td>0.8879</td>
<td>2.38</td>
</tr>
<tr>
<td>C1</td>
<td>0.6344</td>
<td>0.9887</td>
<td>1.5270</td>
<td>1.4380</td>
<td>0.8632</td>
<td>9.60</td>
</tr>
<tr>
<td>C2</td>
<td>0.6763</td>
<td>0.9994</td>
<td>1.4000</td>
<td>1.3940</td>
<td>0.7604</td>
<td>5.28</td>
</tr>
<tr>
<td>C3</td>
<td>0.6182</td>
<td>0.9859</td>
<td>1.5660</td>
<td>1.4370</td>
<td>0.8990</td>
<td>2.40</td>
</tr>
</tbody>
</table>

\[ f = \frac{(BHLC - AHLC)}{BHLC} \]

where BHLC is the building heat loss coefficient and AHLC is the solar aperture heat loss coefficient.

The useful solar heat is \( SHF \) multiplied by the gross heat loss. And finally, the auxiliary heat needed is the gross heat loss minus the useful solar heat.

The above process is repeated for each winter month to obtain the total auxiliary heat. Then, the HHR is the total auxiliary heat divided by the total degree-days, and as before, the HHI is the HHR divided by the floor area.
Table 2. Characteristics of the direct gain systems listed in Table 1

<table>
<thead>
<tr>
<th>System</th>
<th>Area Ratio</th>
<th>Glazings</th>
<th>Night</th>
<th>Insulation</th>
<th>Night Capacity</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>6</td>
<td>2</td>
<td>no</td>
<td>30</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>6</td>
<td>3</td>
<td>no</td>
<td>30</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>6</td>
<td>2</td>
<td>yes</td>
<td>30</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>3</td>
<td>2</td>
<td>no</td>
<td>45</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>3</td>
<td>3</td>
<td>no</td>
<td>45</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>B3</td>
<td>3</td>
<td>2</td>
<td>yes</td>
<td>45</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>6</td>
<td>2</td>
<td>yes</td>
<td>60</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>6</td>
<td>3</td>
<td>no</td>
<td>60</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>6</td>
<td>2</td>
<td>yes</td>
<td>60</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

a The square-footage is the south glazing area.

Related Quantities

There are a number of quantities related to the HHI, such as the Home Heating Requirement, which are also designated by a series of three words (Hodges, 1984b, p. 172). The first word is either End-use, Primary, or Home. The middle word is either Heating, Cooling, or
Energy, and the last word is Requirement, Consumption, Index, or Factor. These terms are defined as follows:

"End-use" quantities include all energy sources delivered to the home without considering efficiency factors.

"Primary" quantities include more than End-use quantities by additionally counting transmission losses en route to the home, generating losses at power plants, transportation of fuel, etc. For Ames, the estimated conversion factors are 110,000 Btu/CCF and 11,000 Btu/kWh.

"Home" quantities count all energy sources delivered to the interior of the home, as defined earlier, and thus efficiency factors are included.

"Heating" quantities refer to space heating during December, January, and February.

"Cooling" quantities refer to summer space cooling, but as yet have not been precisely defined.

"Energy" quantities are also undefined but refer to year-round energy use.

"Requirement" quantities have units of Btu/F°-day or W/C° with the temperature differences based on the home's average indoor temperature.

"Consumption" quantities also have units of Btu/F°-day or W/C°, but the degree-days or C°-s are based on 65°F = 18.3 °C.

"Index" quantities are Requirement quantities divided by the heated floor area and thus have units of Btu/F°-day-ft² or W/C°-m².
"Factor" quantities are Consumption quantities divided by the heated floor area and also have units of Btu/F°-day-ft² or W/°C-m².

Additionally, per-capita quantities can be generated by dividing each Requirement or Consumption by the number of people in the household. A per-capita Index or Factor does not seem to be meaningful.

In comparing the various quantities, it is interesting to note the ways each one can be lowered for a given house. As the Home quantities are independent of the efficiency of the heating system, the only way to lower them is to make improvements on the house itself, such as adding more insulation.

End-use quantities may be lowered by house improvements or increasing the efficiency of the heating system. In gas heated homes, an End-use quantity may actually increase if an inefficient electric appliance is replaced by a more efficient one. The gas furnace will have to burn more gas to make up for the decrease in heat generated by the electric appliance. As a result, the End-use quantity will increase, since the gas furnace has a first-law efficiency less than electric resistance heating.

Primary quantities are more meaningful as they will be lowered by increasing the efficiency of either the heating system or appliances. Also, home improvements and lower transmission losses, etc. will decrease Primary quantities. And of course, all Consumption quantities can be decreased by lower thermostat settings.
In order to compare the HHI with other indices, it is necessary to calculate each index for an example house, and then change various parameters and see what happens. Consider a house with the following characteristics:

1. Two levels, each with dimensions 40 ft. by 28 ft. by 8 ft. high. 
   The bottom level is underground except for the upper 2 ft.
2. 30 ft$^2$ of double-pane windows on each side.
3. The upper level walls are insulated to R-20, basement walls to R-15, the roof to R-30, and windows to R-1.8.
4. The air infiltration rate is one air change per hour.

Home Heating Index

The above house has a HHI of 5.2 Btu/DD-ft$^2$ (1.2 W/C°-m$^2$) assuming weather conditions for an average winter in central Iowa. The HHI of this example house is given under various conditions in Table 3 for each month from October through April. Average indoor temperatures are changed from 60°F to 70°F, assuming no internal heat gains. Next, the internal heat gain is varied from 50,000 Btu/day to 150,000 Btu/day with the average indoor temperature kept at 65°F. In the last three rows, the area of the south-facing windows is changed; for each of these last three cases, the average indoor temperature is 65°F, and the internal heat gain is 50,000 Btu/day.
### Table 3. Home Heating Index in Btu/DD-ft\(^2\) of example house

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>T=60°F</td>
<td>2.6</td>
<td>4.9</td>
<td>5.2</td>
<td>5.1</td>
<td>4.9</td>
<td>4.4</td>
<td>3.2</td>
</tr>
<tr>
<td>T=65°F</td>
<td>3.6</td>
<td>5.0</td>
<td>5.3</td>
<td>5.2</td>
<td>5.0</td>
<td>4.6</td>
<td>3.9</td>
</tr>
<tr>
<td>T=70°F</td>
<td>4.2</td>
<td>5.2</td>
<td>5.3</td>
<td>5.2</td>
<td>5.1</td>
<td>4.8</td>
<td>4.3</td>
</tr>
<tr>
<td>I=50000 Btu/d</td>
<td>3.7</td>
<td>5.0</td>
<td>5.3</td>
<td>5.2</td>
<td>5.0</td>
<td>4.6</td>
<td>3.9</td>
</tr>
<tr>
<td>I=100000 Btu/d</td>
<td>4.1</td>
<td>5.0</td>
<td>5.2</td>
<td>5.1</td>
<td>5.0</td>
<td>4.6</td>
<td>4.1</td>
</tr>
<tr>
<td>I=150000 Btu/d</td>
<td>5.4</td>
<td>4.9</td>
<td>5.2</td>
<td>5.1</td>
<td>4.9</td>
<td>4.6</td>
<td>4.5</td>
</tr>
<tr>
<td>A=0 ft(^2)</td>
<td>4.2</td>
<td>5.2</td>
<td>5.2</td>
<td>5.2</td>
<td>5.1</td>
<td>4.8</td>
<td>4.2</td>
</tr>
<tr>
<td>A=60 ft(^2)</td>
<td>3.3</td>
<td>4.8</td>
<td>5.2</td>
<td>5.0</td>
<td>4.8</td>
<td>4.4</td>
<td>3.7</td>
</tr>
<tr>
<td>A=120 ft(^2)</td>
<td>2.9</td>
<td>4.5</td>
<td>5.0</td>
<td>4.8</td>
<td>4.6</td>
<td>4.1</td>
<td>3.4</td>
</tr>
</tbody>
</table>

In the first six rows the actual structure of the house remains unchanged. Notice that the HHI is relatively constant for the winter months of December through February, varying from 4.9 to 5.3 at the extremes. When the structure of the house is changed slightly in the last three rows, the HHI has a low of 4.6 and a high of 5.2 during the winter months.

Another characteristic of the HHI for this example house is that it decreases in the fall and spring before increasing to infinity during the summer months when there are no heating degree-days. The solar heat
input reaches a minimum in December and then increases for a house, such as this one, with equal window areas on all four sides. Since the solar heat input is at a minimum in December, the auxiliary heating load is at a maximum, causing the HHI to reach a peak. For houses with all their windows on the south side, the daily insolation reaches a maximum in February. The HHI of such a house would increase slowly in the fall and spring before going rapidly to infinity during the summer months. The HHI decreases to zero in the summer months, however, when the internal heat gains are assumed to be zero.

Thermal Integrity Factor

Table 4 lists the Thermal Integrity Factor under the same conditions as the HHI. The two indices are identical for the case when the average indoor temperature is 65°F, and the internal gains are assumed to be zero. However, for the range of indoor temperatures and internal gains considered here, the TIF varies by nearly a factor of two, from 3.3 to 6.0, during the winter months when no changes are made to the house structure. As with the HHI, the TIF reaches a peak in December for reasons described above. The TIF decreases to zero when auxiliary heating is no longer required as is the case for October when the internal heat gain is 150,000 Btu/day.
Table 4. Thermal Integrity Factor of example house

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$T=60^\circ F$</td>
<td>1.5</td>
<td>4.0</td>
<td>4.5</td>
<td>4.5</td>
<td>4.3</td>
<td>3.7</td>
<td>2.2</td>
</tr>
<tr>
<td>$T=65^\circ F$</td>
<td>3.6</td>
<td>5.0</td>
<td>5.3</td>
<td>5.2</td>
<td>5.0</td>
<td>4.6</td>
<td>3.9</td>
</tr>
<tr>
<td>$T=70^\circ F$</td>
<td>5.8</td>
<td>6.1</td>
<td>6.0</td>
<td>5.8</td>
<td>5.7</td>
<td>5.6</td>
<td>5.6</td>
</tr>
<tr>
<td>$I=50000$ Btu/d</td>
<td>1.9</td>
<td>4.2</td>
<td>4.7</td>
<td>4.7</td>
<td>4.4</td>
<td>3.9</td>
<td>2.5</td>
</tr>
<tr>
<td>$I=100000$ Btu/d</td>
<td>0.5</td>
<td>3.4</td>
<td>4.1</td>
<td>4.2</td>
<td>3.9</td>
<td>3.2</td>
<td>1.2</td>
</tr>
<tr>
<td>$I=150000$ Btu/d</td>
<td>0.0</td>
<td>2.6</td>
<td>3.5</td>
<td>3.6</td>
<td>3.3</td>
<td>2.4</td>
<td>0.2</td>
</tr>
<tr>
<td>$A=0$ ft$^2$</td>
<td>2.4</td>
<td>4.4</td>
<td>4.7</td>
<td>4.7</td>
<td>4.6</td>
<td>4.1</td>
<td>2.8</td>
</tr>
<tr>
<td>$A=60$ ft$^2$</td>
<td>1.5</td>
<td>4.0</td>
<td>4.6</td>
<td>4.5</td>
<td>4.3</td>
<td>3.7</td>
<td>2.3</td>
</tr>
<tr>
<td>$A=120$ ft$^2$</td>
<td>1.1</td>
<td>3.7</td>
<td>4.4</td>
<td>4.3</td>
<td>4.0</td>
<td>3.4</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Solar Heating Fraction

The Solar Heating Fraction for the example house is listed in Table 5. When the inside temperature is $60^\circ F$, the SHF is 0.52 in October, but then decreases by a factor of 4 to 0.13 in December. At $70^\circ$ the difference is smaller, but it still changes by more than a factor of two. An internal heat gain of 100,000 Btu/day or more causes the SHF to rise to nearly 1.0 in October, although the SHF during the winter months still remains around 0.15 as it is in the case when the inside
Table 5. Solar Heating Fraction of example house

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>T=60°F</td>
<td>0.52</td>
<td>0.16</td>
<td>0.13</td>
<td>0.14</td>
<td>0.16</td>
<td>0.22</td>
<td>0.40</td>
</tr>
<tr>
<td>T=65°F</td>
<td>0.33</td>
<td>0.15</td>
<td>0.12</td>
<td>0.13</td>
<td>0.15</td>
<td>0.19</td>
<td>0.29</td>
</tr>
<tr>
<td>T=70°F</td>
<td>0.25</td>
<td>0.13</td>
<td>0.11</td>
<td>0.12</td>
<td>0.14</td>
<td>0.17</td>
<td>0.24</td>
</tr>
<tr>
<td>I=50000 Btu/d</td>
<td>0.46</td>
<td>0.16</td>
<td>0.13</td>
<td>0.14</td>
<td>0.16</td>
<td>0.21</td>
<td>0.37</td>
</tr>
<tr>
<td>I=100000 Btu/d</td>
<td>0.99</td>
<td>0.18</td>
<td>0.13</td>
<td>0.14</td>
<td>0.17</td>
<td>0.24</td>
<td>0.53</td>
</tr>
<tr>
<td>I=150000 Btu/d</td>
<td>0.99</td>
<td>0.21</td>
<td>0.15</td>
<td>0.15</td>
<td>0.19</td>
<td>0.28</td>
<td>0.99</td>
</tr>
<tr>
<td>A=0 ft²</td>
<td>0.29</td>
<td>0.10</td>
<td>0.08</td>
<td>0.08</td>
<td>0.10</td>
<td>0.14</td>
<td>0.28</td>
</tr>
<tr>
<td>A=60 ft²</td>
<td>0.99</td>
<td>0.22</td>
<td>0.17</td>
<td>0.19</td>
<td>0.21</td>
<td>0.27</td>
<td>0.46</td>
</tr>
<tr>
<td>A=120 ft²</td>
<td>0.99</td>
<td>0.34</td>
<td>0.26</td>
<td>0.28</td>
<td>0.32</td>
<td>0.39</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Temperature is 60°F with no internal heat gains. The SHF varies by nearly a factor of two during the winter months, when the window area is constant, from 0.11 in December at T=70°F to 0.19 in February when I=150,000 Btu/day.

Changing the south-glazing area also has a dramatic effect on the SHF. When there is no south glazing, the SHF reaches its lowest point at 0.08 during December and January. The SHF then increases by a factor of 3.5 during the same months when the south glazing is 120 ft². Also, it is close to its maximum value of 1.0 in October and April. In each
case, the SHF reaches a minimum in December as the auxiliary heating needs are greatest during this month.

Solar Savings Fraction

The Solar Savings Fraction for the example house is given in Table 6. It takes on values between zero and one as does the SHF, but it shows greater variability than the SHF. In comparing the same two months of October and December when T=60°F, the SSF varies by almost a

Table 6. Solar Savings Fraction of example house

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>T=60°F</td>
<td>0.54</td>
<td>0.13</td>
<td>0.07</td>
<td>0.08</td>
<td>0.12</td>
<td>0.20</td>
<td>0.43</td>
</tr>
<tr>
<td>T=65°F</td>
<td>0.35</td>
<td>0.10</td>
<td>0.06</td>
<td>0.07</td>
<td>0.10</td>
<td>0.17</td>
<td>0.31</td>
</tr>
<tr>
<td>T=70°F</td>
<td>0.25</td>
<td>0.07</td>
<td>0.05</td>
<td>0.06</td>
<td>0.09</td>
<td>0.14</td>
<td>0.23</td>
</tr>
<tr>
<td>I=50000 Btu/d</td>
<td>0.66</td>
<td>0.24</td>
<td>0.16</td>
<td>0.16</td>
<td>0.20</td>
<td>0.30</td>
<td>0.55</td>
</tr>
<tr>
<td>I=100000 Btu/d</td>
<td>0.91</td>
<td>0.39</td>
<td>0.26</td>
<td>0.26</td>
<td>0.31</td>
<td>0.43</td>
<td>0.78</td>
</tr>
<tr>
<td>I=150000 Btu/d</td>
<td>1.00</td>
<td>0.54</td>
<td>0.37</td>
<td>0.35</td>
<td>0.41</td>
<td>0.56</td>
<td>0.96</td>
</tr>
<tr>
<td>A=0 ft²</td>
<td>0.55</td>
<td>0.19</td>
<td>0.13</td>
<td>0.13</td>
<td>0.15</td>
<td>0.24</td>
<td>0.49</td>
</tr>
<tr>
<td>A=60 ft²</td>
<td>0.73</td>
<td>0.30</td>
<td>0.20</td>
<td>0.21</td>
<td>0.25</td>
<td>0.35</td>
<td>0.60</td>
</tr>
<tr>
<td>A=120 ft²</td>
<td>0.83</td>
<td>0.38</td>
<td>0.27</td>
<td>0.29</td>
<td>0.34</td>
<td>0.44</td>
<td>0.68</td>
</tr>
</tbody>
</table>
factor of 8 when the SHF changed by a factor of 4. For the time period of December through February in the first six rows when the south-glazing area remains constant, the SSF goes from a low of 0.05 in December at $T=70^\circ F$ to a high of 0.41 in February at $I=150,000$ Btu/day. This difference is more than an eight-fold increase. The SSF shows less variability than the SHF when the south window area is changed. When $A=120$ ft$^2$, the SSF reaches a maximum of 0.83 and a minimum of 0.27, as opposed to the SHF which reaches a maximum of 0.99 and a minimum of 0.26. As is characteristic of the other solar fractions, the SSF consistently reaches a minimum in December.

Common Solar Fraction

The Common Solar Fraction, listed in Table 7, also takes on values between zero and one, but it is more stable than either the SHF or the SSF. In the first three rows, when the temperature is varied, the CSF is nearly the same as the SHF. For these three cases, the CSF is only 0.04 to 0.10 higher than the SHF for each of the seven months. When the internal heat gain is changed in the next three rows, the low points of the CSF in December and January are roughly twice as high as the low points for the SHF. The same relationship holds true when the south-glazing area is changed. The result is that overall the CSF varies less percentagewise from month to month than the SHF, although the SHF is more consistent in the winter months.
Table 7. Common Solar Fraction of example house

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>T=60°</td>
<td>0.59</td>
<td>0.23</td>
<td>0.17</td>
<td>0.19</td>
<td>0.22</td>
<td>0.29</td>
<td>0.49</td>
</tr>
<tr>
<td>T=65°</td>
<td>0.43</td>
<td>0.20</td>
<td>0.16</td>
<td>0.17</td>
<td>0.20</td>
<td>0.26</td>
<td>0.38</td>
</tr>
<tr>
<td>T=70°</td>
<td>0.34</td>
<td>0.18</td>
<td>0.16</td>
<td>0.17</td>
<td>0.19</td>
<td>0.24</td>
<td>0.32</td>
</tr>
<tr>
<td>I=50000 Btu/d</td>
<td>0.69</td>
<td>0.33</td>
<td>0.25</td>
<td>0.26</td>
<td>0.30</td>
<td>0.38</td>
<td>0.60</td>
</tr>
<tr>
<td>I=100000 Btu/d</td>
<td>0.92</td>
<td>0.46</td>
<td>0.35</td>
<td>0.34</td>
<td>0.39</td>
<td>0.50</td>
<td>0.80</td>
</tr>
<tr>
<td>I=150000 Btu/d</td>
<td>1.00</td>
<td>0.59</td>
<td>0.44</td>
<td>0.42</td>
<td>0.47</td>
<td>0.61</td>
<td>0.96</td>
</tr>
<tr>
<td>A=0 ft²</td>
<td>0.59</td>
<td>0.26</td>
<td>0.21</td>
<td>0.21</td>
<td>0.23</td>
<td>0.31</td>
<td>0.53</td>
</tr>
<tr>
<td>A=60 ft²</td>
<td>0.77</td>
<td>0.39</td>
<td>0.31</td>
<td>0.31</td>
<td>0.35</td>
<td>0.44</td>
<td>0.65</td>
</tr>
<tr>
<td>A=120 ft²</td>
<td>0.86</td>
<td>0.49</td>
<td>0.40</td>
<td>0.41</td>
<td>0.45</td>
<td>0.54</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Passive Heating Ratio

The Passive Heating Ratio of the example house is listed in Table 8. It is identical to the SSF when the internal heat gains are zero, as is the case in the first three rows when only the inside temperature is varied. The PHR reaches a rather low point of less than 0.10 in December and January and remains there when the internal heat gain is increased. In fact, when I=150,000 Btu/day in October, the PHR is nearly equal to zero. This decrease in the PHR is caused by a decrease
in the useful solar heat, and the PHR is zero during the summer months when no solar heat is needed.

As with the other indices that are a function of solar heat input, the PHR fluctuates a great deal when the south-glazing area is enlarged. The PHR increases by a factor of six from 0.03 in December when $A=0 \text{ ft}^2$ to 0.18 when $A=120 \text{ ft}^2$. Even the HHI varies with increasing insolation, as is expected, but certainly not to the degree that the PHR does.

Table 8. Passive Heating Ratio of example house

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$T=60^\circ\text{F}$</td>
<td>0.54</td>
<td>0.13</td>
<td>0.07</td>
<td>0.08</td>
<td>0.12</td>
<td>0.20</td>
<td>0.43</td>
</tr>
<tr>
<td>$T=65^\circ\text{F}$</td>
<td>0.35</td>
<td>0.10</td>
<td>0.06</td>
<td>0.07</td>
<td>0.10</td>
<td>0.17</td>
<td>0.31</td>
</tr>
<tr>
<td>$T=70^\circ\text{F}$</td>
<td>0.25</td>
<td>0.07</td>
<td>0.05</td>
<td>0.06</td>
<td>0.09</td>
<td>0.14</td>
<td>0.23</td>
</tr>
<tr>
<td>$I=50000 \text{ Btu/d}$</td>
<td>0.33</td>
<td>0.10</td>
<td>0.06</td>
<td>0.07</td>
<td>0.11</td>
<td>0.17</td>
<td>0.30</td>
</tr>
<tr>
<td>$I=100000 \text{ Btu/d}$</td>
<td>0.26</td>
<td>0.11</td>
<td>0.06</td>
<td>0.08</td>
<td>0.11</td>
<td>0.17</td>
<td>0.27</td>
</tr>
<tr>
<td>$I=150000 \text{ Btu/d}$</td>
<td>0.03</td>
<td>0.11</td>
<td>0.07</td>
<td>0.08</td>
<td>0.12</td>
<td>0.17</td>
<td>0.20</td>
</tr>
<tr>
<td>$A=0 \text{ ft}^2$</td>
<td>0.22</td>
<td>0.04</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.10</td>
<td>0.23</td>
</tr>
<tr>
<td>$A=60 \text{ ft}^2$</td>
<td>0.42</td>
<td>0.16</td>
<td>0.10</td>
<td>0.12</td>
<td>0.16</td>
<td>0.23</td>
<td>0.36</td>
</tr>
<tr>
<td>$A=120 \text{ ft}^2$</td>
<td>0.53</td>
<td>0.25</td>
<td>0.18</td>
<td>0.20</td>
<td>0.25</td>
<td>0.32</td>
<td>0.44</td>
</tr>
</tbody>
</table>
Fractional Utilization

Fractional Utilization, listed in Table 9, remains relatively steady under different indoor temperatures, but changes much more when the internal heat gain increases. The FU is more than twice as high in December when \( I=150,000 \text{ Btu/day} \) than when \( I=50,000 \text{ Btu/day} \). As with some of the other indices, the FU drops to zero in the summer months, but only when both the gross heat loss and auxiliary heating needs are zero.

Table 9. Fractional Utilization of example house

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( T=60^\circ \text{F} )</td>
<td>0.56</td>
<td>0.56</td>
<td>0.45</td>
<td>0.49</td>
<td>0.56</td>
<td>0.61</td>
<td>0.60</td>
</tr>
<tr>
<td>( T=65^\circ \text{F} )</td>
<td>0.62</td>
<td>0.52</td>
<td>0.43</td>
<td>0.45</td>
<td>0.53</td>
<td>0.59</td>
<td>0.62</td>
</tr>
<tr>
<td>( T=70^\circ \text{F} )</td>
<td>0.62</td>
<td>0.47</td>
<td>0.43</td>
<td>0.43</td>
<td>0.50</td>
<td>0.57</td>
<td>0.62</td>
</tr>
<tr>
<td>( I=50000 \text{ Btu/d} )</td>
<td>1.1</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>( I=100000 \text{ Btu/d} )</td>
<td>1.6</td>
<td>2.1</td>
<td>2.0</td>
<td>1.7</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>( I=150000 \text{ Btu/d} )</td>
<td>1.7</td>
<td>2.9</td>
<td>2.8</td>
<td>2.3</td>
<td>2.1</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>( A=0 \text{ ft}^2 )</td>
<td>1.6</td>
<td>1.8</td>
<td>1.9</td>
<td>1.5</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>( A=60 \text{ ft}^2 )</td>
<td>0.93</td>
<td>1.1</td>
<td>1.1</td>
<td>0.97</td>
<td>0.96</td>
<td>0.97</td>
<td>0.99</td>
</tr>
<tr>
<td>( A=120 \text{ ft}^2 )</td>
<td>0.71</td>
<td>0.94</td>
<td>0.92</td>
<td>0.86</td>
<td>0.85</td>
<td>0.84</td>
<td>0.83</td>
</tr>
</tbody>
</table>
Unlike most of the other indices, FU can vary from zero to values greater than one. For instance, the FU is 0.92 in December when A=120 ft$^2$ and is more than twice as high when there is no south glazing. Overall though, FU seems to show less variability than the other solar heat dependent indices, as it remains fairly constant from month to month for each case considered.

Other Indices

The HHI cannot be easily compared to some of the other indices mentioned earlier. For instance, the Normalized Annual Consumption is based on data from thousands of different homes, and the California Point System is meaningless when studying houses in different climate regions. Other indices, such as the Relative Solar Savings Fraction, are just plain useless. The RSSF is zero for all cases studied, except for changing the south-facing window area, as the windows are evenly distributed around the example house.

Of all the indices compared in Tables 3 through 9, it is clear that the HHI is superior. It remains constant throughout the winter months, and it changes significantly only when the structure of the house is modified.
MEASURING THE HHI

Frequent electric and gas meter readings were obtained from different buildings in Ames, Iowa during the 1984-85 winter to determine how accurately the HHI could be measured, and also to learn how short a time period would be required to measure it with reasonable accuracy. Ten homes and eight student apartments were monitored from the second week in November, 1984 through the third week in March, 1985. Also, 24 all-electric apartments were monitored only during the first three weeks of March. Except for three weeks during December, meter readings were taken daily at the student apartments and several homes but weekly for the rest. Additionally, harsh weather prevented meter readings several times in January and February.

Hourly outside temperature measurements were obtained from the Ames Municipal Power Plant, and these temperatures were assumed to accurately represent the outdoor temperature at each of the monitored buildings (all are in Ames). To determine the average inside temperatures, from three to five thermometers were placed at various locations in each home for a period of one to two weeks, and the residents were asked to record temperatures three times per day. The final data needed were the gas furnace efficiencies, and they were determined from nameplate information and AFUE (Annual Fuel Utilization Efficiency) ratings in several recent editions of the Directory of Certified Furnace and Boiler Efficiency Ratings (GAMA, 1983).
Hodges Residence

The Hodges residence is a two-story superinsulated earth-sheltered direct gain passive solar home. It has a total of 2200 square feet of heated floor area and 440 square feet of south-facing double-pane glazing.

Figure 1 gives the HHI measurements for the Hodges residence for the winter of 1984-85. On the horizontal axis, HHI measurements are grouped in one day intervals, two day intervals, etc. The solid horizontal line indicates the actual HHI for the 3-month period of December through February, and the dashed lines are plus and minus 10% of this value. Vertical lines show the range of measurements for one day readings, etc., and the dot near the center of each line is the average HHI for that grouping. Additionally, error bars represent plus and minus one standard deviation from the average value.

The error bars for one day intervals are quite large, but then shrink to about 20% for weekly measurements. Extreme variations in HHI measurements are expected in a house with a significant solar contribution to the heating load. The solar contribution to the heating load is not counted in the HHI, which results in large fluctuations from sunny days to cloudy days. Also, the Hodges residence contains 120 tons of masonry thermal storage, causing a lower heating requirement on cold cloudy days which follow sunny days.

Previous measurements on this house (Hodges, 1983, p. 247) during the winters of 1979-80, 1980-81, 1981-82, and 1982-83 gave a HHI of 4.3, 2.9, 2.9, and 3.7 Btu/DD-ft² (0.88 W/C°-m²) respectively. Night
Figure 1. HHI measurements of the Hodges residence
insulation on the windows was not used during the first winter, and natural ventilation was increased the fourth winter to study the effects of air infiltration. Also, the fourth winter was much more overcast than normal. A HHI of 3.2 Btu/DD-m\(^2\) (0.76 W/C°-m\(^2\)) for the 1984-85 winter agrees closely with the previous measurements.

Pyle Residence

The Pyle residence is a single-story superinsulated home with a full basement. It has 3000 square feet of heated floor space at an average temperature of 63.9°F. As shown in Figure 2, the Pyle residence is the most efficient of the homes surveyed with a HHI of 2.0 Btu/DD-ft\(^2\) (0.47 W/C°-m\(^2\)).

Even though the house is very energy efficient, it only has an average amount of south-glazing. The lack of abundant solar heat has resulted in consistent HHI measurements, to within about 10%, at three-day intervals or greater. The large variation in seven-day readings can be explained by the occupants' behavior. A single woman occupied the house when daily meter readings were taken through mid-January. Weekly readings were taken for the remainder of the winter, but the woman was married at about the same time the daily readings ended. It appears that the married couple preferred a higher average indoor temperature, thus skewing the HHI measurements upward.

The builder of the Pyle residence, Buck Construction Company, calculated and then advertised the HHI to be 2.2. However, after the measurements were taken, the builder confessed that the original
Figure 2. HHI measurements of the Pyle residence
calculations gave a HHI of 2.0, and the numbers were "fudged" because he did not think anyone would believe him. Either way, the predicted HHI is close to the measured HHI.

**Bremner Residence**

Figure 3 shows the results of measurements on the Bremner residence. This two-story townhouse contains 2045 square feet of heated floor space at an average temperature of 69.4°F. The bottom floor is mostly underground except for the south side which has a large window area. The variation in HHI measurements seems to have dropped to a minimum at three-day intervals and then remained at that level. Notice that the averages for one-day readings through weekly readings are all below the actual HHI of 3.3 Btu/DD-ft² (0.78 W/C°-m²). The HHI during Christmas vacation, when no meter readings were taken, must have been higher than normal.

**Buildings Monitored Weekly**

Figure 4 shows the HHI for six buildings monitored weekly. The first one is the Selman residence, which is a superinsulated passive solar two-story home with a small basement. It has 1890 square feet of heated floor area at an average temperature of 69.5°F. Its HHI was predicted to be 4.5 Btu/DD-ft² (1.1 W/C°-m²), but the measured HHI is 4.9 Btu/DD-ft² (1.2 W/C°-m²), which is still within 10% of the predicted value. Some of the uncertainty in the measurements is due to the residents burning slightly less than one cord of wood during the winter
Figure 3. HHI measurements of the Bremner residence
at uneven intervals. Also, the HHI appears to have been lower during Christmas vacation than the average weekly measurements.

The second building represented in Figure 4 is the Twin Oaks apartment building. This all-electric building contains 24 apartments with an average floor area of 720 square feet apiece. All numbers represent the HHF, not HHI, for the entire building, since it would not be practical to monitor the temperature in each individual apartment. A large portion of the spread in HHF values is probably a result of students leaving during spring break vacation and on weekends.

Building number 3 is the Friedrich residence, which is a superinsulated passive solar two-story home with a basement. It contains 3073 square feet of floor space at an average temperature of 69.1°F. This home's HHI was calculated to be 3.1 Btu/DD-ft² (0.73 W/°C-m²) before the winter began, but the measured value is 50% higher. Some improvements near the end of winter, which reduced the air infiltration, lowered the HHI to about 4.2 Btu/DD-ft² (0.99 W/°C-m²). An estimated air infiltration of 0.5 air changes per hour may have been overly optimistic considering that there are three children in the family.

Number 4 is the Olson residence, which is also a superinsulated passive solar two-story home with a full basement. This large home has 4900 square feet of floor area at an average temperature of 69.5°F. The heating system consists of a heat pump, with a coefficient of performance of 2.9, plus a fireplace. The average of the weekly measurements is 4.8 Btu/DD-ft² (1.1 W/°C-m²), or almost 10% higher than
Figure 4. Weekly HHI measurements of six buildings
the actual HHI. As with the Selman residence, the HHI during Christmas vacation must have been lower than average.

The fifth home, with a HHI of 4.3 Btu/DD-ft$^2$ (1.0 W/C°-m$^2$), is the Osterberg residence. This passive solar 5178 square-foot home has two levels plus a full basement with an overall average temperature of 64.5°F. During the winter, temperatures in the basement hovered in the upper 50s while temperatures of the two floor levels varied from upper 50s to upper 70s. This large variation in temperatures is natural for homes with a significant solar energy input, and this solar heating causes a wider spread in HHI measurements.

The last home is the Karas residence, a 3070 square-foot townhouse built by the same construction company as the Bremner townhouse and the Pyle residence. This passive solar two-story home has a full basement and was heated to an average temperature of 64.4°F, yielding a HHI of 3.8 Btu/DD-ft$^2$ (0.90 W/C°-m$^2$). Most of the weekly readings fall within one standard deviation of the actual HHI.

Other Monitored Homes

The HHI of the Barnes residence and Leacock residence were also measured. The Barnes house uses propane gas for heating, and it was impossible to get dependable weekly measurements due to an inaccurate gauge on the gas tank. Overall, the Barnes house did quite well with a measured HHI of 3.2 Btu/DD-ft$^2$ (0.76 W/C°-m$^2$), which is rather close to a predicted HHI of 3.3 Btu/DD-ft$^2$ (0.78 W/C°-m$^2$) calculated from construction drawings.
The Leacock residence was included since it is an older house and was expected to be energy inefficient with an HHI perhaps around 8.0 Btu/DD-ft² (1.9 W/C°-m²). The actual measured HHI turned out to be 6.8 Btu/DD-ft² (1.6 W/C°-m²), a value which is still higher than that of any other single-family dwelling in this survey.

University Village Student Apartments

Building number 103 of University Village contains four two-story 708 square-foot adjacent apartments with 103A on the south end and 103D on the north end. Figures 5 through 8 show the HHP for each individual apartment, and Figure 9 gives the HHP of the entire building.

103A has the same general trend as the houses in the survey, with the spread in HHP measurements reaching a minimum for three-day readings and remaining constant for longer time periods. 103D shows a little more variation, with the minimum at four-day intervals. Apartment 103B has a minimum at three days, but then the error bars increase slightly for four or more days. Finally, 103C shows no consistent pattern, while its HHP of 4.7 Btu/DD-ft² (1.1 W/C°-m²) is the lowest of the four.

The greater variation in the HHP for the two inner apartments is expected since they each share a wall with two other apartments, while the units on the end only share a single wall. It also seems that the two inner apartments should have lower HHI values, and on the average lower HHP values. The HHP for 103C appears to be anomalously low, although the same apartment had a HHP of 6.3 Btu/DD-ft² (1.5 W/C°-m²) the previous winter when a different family occupied the place. The
Figure 5. HHF measurements of University Village #103A
Figure 6. HHF measurements of University Village #103B
Figure 7. HHF measurements of University Village #103C
Figure 9. HHF measurements of University Village #103
more recent family evidently prefers a rather low indoor temperature compared to the others. As a result, there is a net heat flow into their apartment from both adjacent apartments through the shared walls.

The building as a whole is similar to a one family house in that the error bars reach a minimum at three days. Also, its HHF for the winter of 1983-84 was 7.7 Btu/DD-ft² (1.8 W/C⁰-m²), which is within 10% of the 1984-85 HHF.

Schillletter Village Student Apartments

Building number 62 of Schillletter Village contains four 666-square-foot student apartments. Apartments A and B are on the ground floor with A on the west side and B on the east, while C and D are on the second floor with C on the west side and D on the east side. Figures 10 through 13 show the HHF for each individual apartment, and Figure 14 gives the HHF for the entire building.

On the average, one would expect apartments C and D to have higher HHF values since a larger portion of their envelopes are exposed to the outdoor air. Apartment C has the highest HHF in building 62, although apartment D has the lowest. However, the average HHF of C and D is 0.45 higher than the average of A and B. The HHF graph of each individual apartment varies according to the occupants' living patterns and is also dependent to some extent on their neighbor's patterns.

The building as a whole shows an interesting trend. Variation in the HHF reaches a minimum at three or four day intervals, but then steadily increases through seven-day readings. Errors in meter readings
Figure 10. HHF measurements of Schilletter Village #62A
Figure 11. HHF measurements of Schilletter Village #62B
Figure 12. HHF measurements of Schilletter Village #62C
Figure 13. HHF measurements of Schilletter Village #62D
Figure 14. HHF measurements of Schilletter Village #62
have been minimized by day three, but beyond that there is an increasing probability of the reading overlapping a weekend. Most people have different schedules on weekends and holidays; either going out or inviting people over, etc. It seems that overall the four families in this building had significantly different weekend schedules, more so than any other families in this survey.

Student Apartments HHF (Winter 1983-84)

Tables 10 through 12 list the HHF for a sample of student apartments in Hawthorn Court, Schilletter Village, and University Village for the winter of 1983-84. The HHF was calculated from utility bills provided by Iowa State University. In University Village, units 101 to 145 were built first in phase 1 while units 146 to 173 were constructed later in phase 2. The most energy efficient of all the student apartments are those in University Village phase 2 with an average HHF of 7.0 Btu/DD-ft\(^2\) (1.7 W/C\(^0\)-m\(^2\)) followed by phase 1 with a HHF of 7.9 Btu/DD-ft\(^2\) (1.9 W/C\(^0\)-m\(^2\)). Hawthorn Court and Schilletter Village are nearly tied for last place with a HHF of 9.1 Btu/DD-ft\(^2\) (2.2 W/C\(^0\)-m\(^2\)) and 9.2 Btu/DD-ft\(^2\) (2.2 W/C\(^0\)-m\(^2\)) respectively.

A general trend shown in the tables is the monthly variation in the HHF for each building. Most buildings have a slightly lower HHF in January than in December and the highest HHF in February. This trend is most likely due to students leaving during Christmas vacation which started December 17, 1983 and ended January 17, 1984.

Another pattern is evident in the HHF of apartments on the end of
Table 10. Home Heating Factor for Hawthorn Court student apartments during the winter of 1983-84

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Table 11. Home Heating Factor of Schilletter Village student apartments for the winter of 1983-84

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Table 12. Home Heating Factor of University Village student apartments for the winter of 1983-84

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buildings versus those in the middle. In the University Village phase 2 units, the exterior apartments have an average HHP of 7.7 Btu/DD-ft² (1.8 W/C°-m²), while those in the interior have a HHP of 6.7 Btu/DD-ft² (1.6 W/C°-m²). For phase 1 units it is 8.4 Btu/DD-ft² (2.0 W/C°-m²) and 7.4 Btu/DD-ft² (1.8 W/C°-m²), and for Hawthorn Court it is 9.7 Btu/DD-ft² (2.3 W/C°-m²) and 8.5 Btu/DD-ft² (2.0 W/C°-m²). In Schilletter Village, the apartments on the lower floor have an average HHP of 8.3 Btu/DD-ft² (2.0 W/C°-m²) and those on the upper floor 9.8 Btu/DD-ft² (2.3 W/C°-m²).

The differences in the efficiencies of the various buildings, and apartments within buildings, can add up to significantly higher fuel bills for some families. An increase of one Btu/DD-ft² in the HHP for a 700 square-foot apartment over an average winter of 3783 degree-days (December 1 through February 28) results in an additional fuel cost for a 3-month period of $35, assuming $.80 per CCF and a gas furnace with a 60% burning efficiency.

Comparison With Results From Two Random Surveys

A survey (Hodges, 1984a, p. 268) of 440 randomly-selected central Iowa homes was undertaken to determine the average HHI of existing dwellings. In this survey, HHI values ranged from a low of 2.9 Btu/DD-ft² (0.69 W/C°-m²) to a high of 21.5 Btu/DD-ft² (5.1 W/C°-m²) with the average HHI being 8.2 Btu/DD-ft² (1.9 W/C°-m²).

A second survey was taken of 50 newer homes built in 1981 and 1982. This group of homes had an average HHI of 6.2 Btu/DD-ft² (1.5 W/C°-m²),
which is 76% of the average HHI in the previous survey. The lowest HHI
was 2.7 Btu/DD·ft² (0.64 W/C°·m²) and the highest was 9.3 Btu/DD·ft²
(2.2 W/C°·m²). The three most efficient dwellings were passive solar
homes with HHI values of 2.7, 3.5, and 4.0 Btu/DD·ft² (0.95 W/C°·m²). Two active solar homes both had a HHI of 5.8 Btu/DD·ft² (1.4 W/C°·m²).

An interesting comparison can be made between the HHI of homes monitored during the winter of 1984-85 and the results of the above surveys. The Pyle residence, with a HHI of 2.0 Btu/DD·ft² (0.47 W/C°·m²), is more efficient than any of the homes in either survey. All of the monitored houses, except the Leacock residence, are more efficient than the average home in the second survey. The Leacock residence, with a HHI of 6.8 Btu/DD·m² (1.6 W/C°·m²), is more efficient than the average house in the first survey, but less efficient than the average house in the second survey. Similarly, the average HHP of the University Village student apartments falls between the average values of the two surveys. Although in one case a HHI was calculated and in the other it is a HHP, a meaningful comparison can still be made as most people keep their homes heated close to 65°F. At the bottom of the list, the student apartments in Hawthorn Court and Schilletter Village are less efficient than the average house in the first survey of older homes. In fact, with a HHP of 9.1 Btu/DD·ft² (2.2 W/C°·m²) and 9.2 Btu/DD·ft² (2.2 W/C°·m²), Hawthorn Court and Schilletter Village are nearly as inefficient as the most inefficient house in the second survey of newer homes.
EFFECTS OF WIND AND INSOLATION ON THE HHI

Either an increase in wind speed or a decrease in insolation will increase the HHI of a building. A higher wind speed increases the air infiltration rate, which contributes significantly to the heat loss rate of most buildings, thereby increasing the HHI. Also, a higher wind speed will decrease the thickness of the boundary layer of air on the outside of a wall, roof, or window, thereby lowering the effective R-value. A drop in the amount of insolation on a building will lower the amount of solar heat input, causing an increase in the auxiliary heat requirements and thus raising the HHI.

Effects of Wind on the HHI

Table 13 shows the effects of wind on HHI measurements of five buildings. For each residence, the daily HHI measurements are divided into two groups of approximately equal size, such that the average daily wind speed is less than 10 mph for one group and greater than 13 mph for the other group. Average wind speeds of each group are given as is the standard deviation of the mean for each group. The wind speeds are actually for Des Moines (National Oceanic and Atmospheric Administration, November 1984 through March 1985), but are assumed to be close enough to wind speeds in Ames for the purposes of this study.

There seems to be little or no effect of wind on the HHI of the first two residences, as the standard deviations of the means overlap
Table 13. Effects of wind speed on residences monitored during the winter of 1984-85

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<td>standard deviation</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>of the HHI mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>University Village #103</td>
<td></td>
<td></td>
</tr>
<tr>
<td>average wind speed</td>
<td>8.4</td>
<td>14.7</td>
</tr>
<tr>
<td>average HHF</td>
<td>7.0</td>
<td>7.6</td>
</tr>
<tr>
<td>standard deviation</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>of the HHF mean</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 13 (continued)

<table>
<thead>
<tr>
<th>Residence</th>
<th>Wind speed &lt; 10 mph</th>
<th>Wind speed &gt; 13 mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schilletter Village #62:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>average wind speed</td>
<td>8.4</td>
<td>14.7</td>
</tr>
<tr>
<td>average HHP</td>
<td>9.0</td>
<td>10.5</td>
</tr>
<tr>
<td>standard deviation</td>
<td>0.4</td>
<td>0.3</td>
</tr>
</tbody>
</table>

of the HHP mean

Each other. The difference is more pronounced for the Bremner residence and University Village #103, while the effect is sizable for Schilletter Village #62. An increase of 6.3 mph in wind speed at #62 adds 1.5 to the HHP. These results are expected as both the Hodges and Pyle residences are "tight" with low air infiltration rates, thereby minimizing the effects of wind speed. Schilletter Village #62 on the other hand is a very "loose" building, and thus an increase in wind speed significantly increases its HHP.

Effects of Insolation on the HHI

Table 14 indicates the effects of insolation on the same five buildings. The Hodges residence shows the most dramatic variation with a tripling of the insolation decreasing the HHI by more than half. The effect is most noticeable here, because solar heat contributes a
Table 14. Effects of insolation on residences monitored during the winter of 1984-85

<table>
<thead>
<tr>
<th>Residence</th>
<th>Daily Horizontal Insolation (Btu/ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I &lt; 400</td>
</tr>
<tr>
<td>Hodges:</td>
<td></td>
</tr>
<tr>
<td>average insolation</td>
<td>215</td>
</tr>
<tr>
<td>average HHI</td>
<td>4.7</td>
</tr>
<tr>
<td>standard deviation</td>
<td>0.3</td>
</tr>
<tr>
<td>of the HHI mean</td>
<td></td>
</tr>
<tr>
<td>Pyle:</td>
<td>I &lt; 500</td>
</tr>
<tr>
<td>average insolation</td>
<td>424</td>
</tr>
<tr>
<td>average HHI</td>
<td>2.1</td>
</tr>
<tr>
<td>standard deviation</td>
<td>0.1</td>
</tr>
<tr>
<td>of the HHI mean</td>
<td></td>
</tr>
<tr>
<td>Bremner:</td>
<td>I &lt; 600</td>
</tr>
<tr>
<td>average insolation</td>
<td>478</td>
</tr>
<tr>
<td>average HHI</td>
<td>3.4</td>
</tr>
<tr>
<td>standard deviation</td>
<td>0.2</td>
</tr>
<tr>
<td>of the HHI mean</td>
<td></td>
</tr>
<tr>
<td>University Village #103</td>
<td>I &lt; 600</td>
</tr>
<tr>
<td>average insolation</td>
<td>478</td>
</tr>
<tr>
<td>average HHF</td>
<td>7.2</td>
</tr>
<tr>
<td>standard deviation</td>
<td>0.3</td>
</tr>
<tr>
<td>of the HHF mean</td>
<td></td>
</tr>
</tbody>
</table>
Table 14 (continued)

<table>
<thead>
<tr>
<th>Residence</th>
<th>Daily Horizontal Insolation (Btu/ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schilletter Village #62:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I &lt; 600</td>
</tr>
<tr>
<td></td>
<td>I &gt; 800</td>
</tr>
<tr>
<td>average insolation</td>
<td>478</td>
</tr>
<tr>
<td>average HHF</td>
<td>10.1</td>
</tr>
<tr>
<td>standard deviation</td>
<td>0.4</td>
</tr>
<tr>
<td>of the HHF mean</td>
<td></td>
</tr>
<tr>
<td></td>
<td>983</td>
</tr>
<tr>
<td></td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
</tr>
</tbody>
</table>

A significant portion of the heating needs due to the large south-glazing area. Although there is less south-glazing than at the Hodges residence, a doubling of the insolation at the Bremner residence has reduced the HHI by about 25%. Since the Pyle residence has little south glazing, the HHI varies negligibly with increasing insolation. Recall that this house's HHI also varies little with increasing wind speed, and thus its HHI seems to be independent of weather conditions.

Both student apartment buildings have small glazing areas, and therefore an increase in incident solar radiation has little effect on the HHF. At University Village #103, the HHF actually increases slightly with a doubling of the insolation. This is most likely due to a statistical fluctuation as the standard deviations of the means overlap each other. Finally, the HHF of Schilletter Village #62
decreases by 0.5 with a doubling of the insolation, but the effect is not statistically significant.
PERFORMANCE OF SOLAR HOMES CALCULATED FROM DATA IN THE LITERATURE

There are a number of papers on solar homes that give enough data to calculate the HHI. Some have very low HHI values and are very energy efficient. Others claim to be energy efficient, based on other indices, but have high HHI values. One of the more famous homes is the Kelbaugh house.

Kelbaugh House

The Kelbaugh house (Kelbaugh, 1978, p. 69) is located in Princeton, New Jersey. It receives most of its solar heat through a passive solar heating system consisting of a Trombe wall and greenhouse. The total floor area of this two-story house is 1850 square feet, including a 200 square-foot greenhouse. There were a total of 5556 degree-days, based on an average indoor temperature of 65°F, for the winter of 1976-77, although Kelbaugh does not state in his paper the precise dates the degree-days were measured. He does take into account the efficiency of his gas furnace and includes all sources of heat delivered to the interior of his house. His measured heat input of 31,250,000 Btu gives a HHI of 3.0 Btu/DD-ft² (0.71 W/C°-m²) for the 1976-77 winter. This may be a slight overestimate, as milder months were probably included with colder months.
Balcomb House

Another famous solar home is the Balcomb house (Balcomb et al., 1980) located in Santa Fe, New Mexico. This two-story building has 1959 square feet of living area plus an attached 344 square-foot greenhouse. An adobe wall between the greenhouse and living space is used for heat storage. The house was carefully monitored between November 1, 1978 and April 24, 1979 with a resulting HHI of 2.9 Btu/DD-ft² (0.69 W/C⁰-m²) for that time period.

Adjacent Conventional House and Passive Solar House

A conventional house and a superinsulated passive solar house were built side by side in Newport, Vermont (Hamilton and Sachs, 1982, p. 21). Both homes have the same 1318 square-foot floor plan and are nearly identical in appearance.

The conventional home is a three bedroom ranch style with a full basement and has an attached, unheated garage. Windows are double-glazed and the walls have 6 inches of fiberglass insulation and the ceiling 12 inches. The uninsulated basement was kept at 50⁰F during the winter, and the rest of the house was maintained at 72⁰F. A blower door pressurization test yielded an air infiltration rate of 0.71 air changes per hour.

All windows are triple-glazed in the solar house and it has 75% more south-facing glazing, but this still amounts to only 7% of the heated floor area. There are 2 inches of Styrofoam insulation on the outside of the basement walls and 4 inches on the above-ground walls.
The double-stud walls contain three layers of fiberglass insulation, each of which is 3.5 inches thick, while the ceiling has 15 inches of fiberglass. A continuous polyethylene vapor barrier helps keep the air infiltration down to 0.20 air changes per hour.

Results for winter, 1982 are listed in Table 15. Both houses were monitored every 15 seconds to measure directly the heat delivered to the living space from both auxiliary and internal heating. It is not possible to calculate the HHI for either of these houses since the degree-days are not given. However both homes experienced the same weather, and therefore it can be seen from Table 15 that the solar home's HHI is approximately 40% of the conventional home's HHI.

Table 15. Energy consumption of adjacent conventional and solar homes

<table>
<thead>
<tr>
<th>Month</th>
<th>Conventional Btu/ft²</th>
<th>Solar Btu/ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>January, 1982</td>
<td>13,600</td>
<td>5,900</td>
</tr>
<tr>
<td>February</td>
<td>10,200</td>
<td>3,900</td>
</tr>
<tr>
<td>March</td>
<td>8,900</td>
<td>3,400</td>
</tr>
</tbody>
</table>
Water-Wall House

The Geisel house (Fraker and Lindsey, 1979, p. 659) is located in Princeton, New Jersey and uses a glazed water-wall for passive solar heating and thermal storage. This two-story all-electric building is earth bermed on the north side and has 2880 square feet of heated floor area. The average indoor temperature is unknown, so only the HHP is calculated in Table 16.

Table 16. HHP of a water-wall house

<table>
<thead>
<tr>
<th>Month</th>
<th>Degree-days (65°F base)</th>
<th>Btu delivered (Btu/DD-ft²)</th>
<th>HHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>November, 1978</td>
<td>521</td>
<td>3.8 x 10⁶</td>
<td>2.5</td>
</tr>
<tr>
<td>December</td>
<td>824</td>
<td>4.5 x 10⁶</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Tightly Sealed Houses

A superinsulated passive solar house has been carefully built and monitored in Eagan, Minnesota (Robinson, 1979, p. 703). There are 1800 square feet of heated floor area and 90 square feet of south facing double glazed windows. One-half of the lower level of this two-story house is below ground, which reduces both heat losses and air infiltration.

Additional characteristics which reduce air infiltration include:
exterior openings well-caulked, 4 mil polyethylene vapor barrier, house sheathed with tongue and groove polystyrene, exterior plywood siding, exterior doors equipped with magnetic seals, and a double door entrance which provides an air lock entry into the house. The air infiltration rate as measured by an ethane gas tracer technique is 0.12 air changes per hour in a 15 mph wind.

The HHI of this house was measured to be 2.3 Btu/DD-ft\(^2\) (0.54 W/°C-m\(^2\)) from tests carried out with an electric furnace, but its HHI was 1.6 Btu/DD-ft\(^2\) (0.38 W/°C-m\(^2\)) when calculated from utility bills. This discrepancy may have been caused by an incorrect estimate of the heating system's efficiency, or perhaps it was cloudy when the tests were performed.

An even tighter building is the Saskatchewan Conservation House (Besant et al., 1979, p. 713). The infiltration in this house was measured using a tracer gas technique to be 0.05 air changes per hour. Since this house has only been operated as a demonstration dwelling, it is not possible to calculate its HHI.

Simply because a house has a low infiltration rate does not mean it has an unusually low HHI. An example is provided by a single-story 1180 square-foot test home in Portland, Oregon (Tsongas et al., 1983, p. 321). This house has typical wood frame construction and 105 square feet of single-pane glazing on the south side. The home was built carefully to insure a low infiltration rate, and a blower door test determined an infiltration rate of 0.11 air changes per hour. However, the HHI turned out to be 4.0 Btu/DD-ft\(^2\) (0.95 W/°C-m\(^2\)) as shown in
Table 17. The use of single rather than double glazing may have caused this poorer performance.

Table 17. Home Heating Index of a tightly sealed house

<table>
<thead>
<tr>
<th>Month</th>
<th>Degree-days</th>
<th>Btu</th>
<th>HHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>November, 1982</td>
<td>573</td>
<td>2.0 x 10^6</td>
<td>2.9</td>
</tr>
<tr>
<td>December</td>
<td>595</td>
<td>2.2 x 10^6</td>
<td>3.1</td>
</tr>
<tr>
<td>January, 1983</td>
<td>586</td>
<td>3.3 x 10^6</td>
<td>4.8</td>
</tr>
<tr>
<td>February</td>
<td>495</td>
<td>2.5 x 10^6</td>
<td>4.3</td>
</tr>
<tr>
<td>March</td>
<td>517</td>
<td>2.2 x 10^6</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Double Envelope House

A passive solar/double envelope home in Duluth, Minnesota (Williams, 1981, p. 30) has three levels and a total floor area of 3000 square feet. Much of the basement is below ground and is designed to store heat along with a 12-inch-thick mass wall. 100 probes installed in the house recorded energy usage and temperatures at various points. Recorded temperatures in the envelope cavity and basement seem to show that the basement walls, slabs, and enclosed berm act as a heat sink rather than a heat source at night.

Table 18 gives the HHF for the winter of 1980-81.
Table 18. Home Heating Factor of a double envelope house

<table>
<thead>
<tr>
<th>Month, 1980</th>
<th>Degree-days</th>
<th>Btu</th>
<th>HHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>November</td>
<td>1047</td>
<td>11.5 x 10^6</td>
<td>3.7</td>
</tr>
<tr>
<td>December</td>
<td>1649</td>
<td>14.3 x 10^6</td>
<td>2.9</td>
</tr>
<tr>
<td>January</td>
<td>1655</td>
<td>13.5 x 10^6</td>
<td>2.7</td>
</tr>
<tr>
<td>February</td>
<td>1325</td>
<td>10.5 x 10^6</td>
<td>2.6</td>
</tr>
<tr>
<td>March</td>
<td>1106</td>
<td>5.6 x 10^6</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Poor Solar Homes

An example of a poor solar house is a two-story 1000 square foot home in Waitsfield, Vermont (Dubin and Tucker, 1979, p. 541). The passive solar system consists of a Trombe wall with 220 square feet of vertical south glazing and 58 square feet of south glazing tilted at 53° from the horizontal. A concrete block wall four feet behind the glass is used for heat storage.

Partial data for the winter of 1977-78 are listed in Table 19. Neither internal gains nor heat from a wood burning stove are included in the Btu total. Thus, the actual HHI is probably much higher.

Not only is the house rather inefficient for a passive solar design, but it is uncomfortable as well. Since no movable insulation is
used on the windows, temperatures near the storage wall range from a low of 38°F in the winter to a high of 110°F in the summer. Overall, this house certainly does not live up to its design expectations. The home may have a larger than normal ratio of envelope area to floor area, because it is small but two-story.

Table 19. Auxiliary Home Heating Index of a poor solar home

<table>
<thead>
<tr>
<th>Month</th>
<th>Degree-days</th>
<th>Btu</th>
<th>Aux. HHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>December, 1977</td>
<td>1643</td>
<td>8.1 x 10^6</td>
<td>4.9</td>
</tr>
<tr>
<td>January, 1978</td>
<td>1612</td>
<td>8.4 x 10^6</td>
<td>5.2</td>
</tr>
</tbody>
</table>

The owner of a 1168 square-foot home with attached greenhouse and Trombe wall in Knoxville, Tennessee (Barth, 1979, p. 648) is evidently

Table 20. Home Heating Factor of a solar home in Knoxville, Tennessee

<table>
<thead>
<tr>
<th>Month</th>
<th>Degree-days</th>
<th>Btu</th>
<th>SHF</th>
<th>HHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>November, 1978</td>
<td>310</td>
<td>1.3 x 10^6</td>
<td>0.98</td>
<td>3.6</td>
</tr>
<tr>
<td>December</td>
<td>681</td>
<td>4.4 x 10^6</td>
<td>0.65</td>
<td>5.5</td>
</tr>
</tbody>
</table>
rather satisfied with his home based on SHF calculations. Perhaps he would not be quite so content if he knew his HMF listed in Table 20.

Yet another lower efficiency building in Knoxville is a passive solar modular house (Reid et al., 1982, p. 747). It has 1200 square feet of floor area and 144 square feet of south glazing. The heat storage system consists of 20 translucent tubes, each filled with 33.8 gallons of water. This house is considered efficient because its solar collection efficiency (net solar gain divided by available solar) is 64%, and its solar fraction (net solar gain divided by auxiliary plus net solar gain) equals 0.40.

Since only the auxiliary heat was given, and not the internal gains, only an auxiliary HHI can be calculated in Table 21. The actual HHI would be higher, and it is already above 5.0 Btu/DD-ft$^2$ (1.2 W/C°-m$^2$) for January plus February.

Table 21. Auxiliary HHI of a solar home in Knoxville, Tennessee

<table>
<thead>
<tr>
<th>Month</th>
<th>Degree-days</th>
<th>Btu</th>
<th>Aux. HHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>January, 1982</td>
<td>1026</td>
<td>$7.7 \times 10^6$</td>
<td>6.3</td>
</tr>
<tr>
<td>February</td>
<td>653</td>
<td>$3.7 \times 10^6$</td>
<td>4.7</td>
</tr>
</tbody>
</table>
Six Passive Solar Homes in Denver, Colorado

Table 22 summarizes information on six passive solar homes in Denver, Colorado (Swisher, 1982, p. 783). All of the buildings are wood-frame, heavily insulated, low-mass designs, and use double-glazed windows.

22 different measurements were performed on each building every 15 seconds. Some of these measurements, along with the HHI, are presented in Table 23. Notice that for most homes the HHI remains fairly constant from December through February and is lower in November and March.

Table 22. Characteristics of six passive solar homes in Denver

<table>
<thead>
<tr>
<th>House</th>
<th>Alpert</th>
<th>Arnold</th>
<th>Ferguson</th>
<th>Heritage</th>
<th>Klaus</th>
<th>Walden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor area (ft²)</td>
<td>1527</td>
<td>2590</td>
<td>2820</td>
<td>1684</td>
<td>1376</td>
<td>1873</td>
</tr>
<tr>
<td>Lower level</td>
<td>basement</td>
<td>basement</td>
<td>bermed</td>
<td>ground</td>
<td>ground</td>
<td>basement</td>
</tr>
<tr>
<td>Solar system gain</td>
<td>0.64</td>
<td>0.32</td>
<td>0.70</td>
<td>0.58</td>
<td>0.72</td>
<td>0.70</td>
</tr>
<tr>
<td>Air changes/hour</td>
<td>0.64</td>
<td>0.32</td>
<td>0.70</td>
<td>0.58</td>
<td>0.72</td>
<td>0.70</td>
</tr>
</tbody>
</table>
Table 23. Home Heating Index of six passive solar homes in Denver

<table>
<thead>
<tr>
<th>Month</th>
<th>Degree-days</th>
<th>MBtu</th>
<th>HHI</th>
<th>Alpert HHI = 3.5</th>
<th>Degree-days</th>
<th>MBtu</th>
<th>HHI</th>
<th>Arnold HHI = 3.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>November</td>
<td>821</td>
<td>3.4</td>
<td>2.7</td>
<td>869</td>
<td>6.1</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>1032</td>
<td>5.6</td>
<td>3.6</td>
<td>1127</td>
<td>11.0</td>
<td>3.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>1066</td>
<td>5.9</td>
<td>3.6</td>
<td>1205</td>
<td>10.3</td>
<td>3.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>1028</td>
<td>5.1</td>
<td>3.3</td>
<td>1043</td>
<td>8.5</td>
<td>3.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>887</td>
<td>4.4</td>
<td>3.3</td>
<td>815</td>
<td>5.6</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Month</th>
<th>Degree-days</th>
<th>MBtu</th>
<th>HHI</th>
<th>Ferguson HHI = 2.4</th>
<th>Degree-days</th>
<th>MBtu</th>
<th>HHI</th>
<th>Heritage HHI = 3.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>November</td>
<td>751</td>
<td>0.7</td>
<td>0.3</td>
<td>724</td>
<td>3.5</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>1004</td>
<td>6.4</td>
<td>2.3</td>
<td>915</td>
<td>7.8</td>
<td>5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>1038</td>
<td>5.9</td>
<td>2.0</td>
<td>887</td>
<td>4.5</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>1068</td>
<td>8.7</td>
<td>2.9</td>
<td>867</td>
<td>4.1</td>
<td>2.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>943</td>
<td>8.3</td>
<td>3.1</td>
<td>703</td>
<td>4.2</td>
<td>3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Month</td>
<td>Degree-days</td>
<td>Mbtu</td>
<td>HHI</td>
<td>Degree-days</td>
<td>Mbtu</td>
<td>HHI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>------</td>
<td>-----</td>
<td>-------------</td>
<td>------</td>
<td>-----</td>
<td></td>
<td></td>
</tr>
<tr>
<td>November</td>
<td>745</td>
<td>1.1</td>
<td>1.1</td>
<td>886</td>
<td>5.8</td>
<td>3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>1122</td>
<td>2.9</td>
<td>1.9</td>
<td>882</td>
<td>8.4</td>
<td>5.1</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>1088</td>
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<td>2.0</td>
<td>988</td>
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<td>942</td>
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<td>932</td>
<td>6.7</td>
<td>3.8</td>
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<tr>
<td>March</td>
<td>787</td>
<td>2.1</td>
<td>1.9</td>
<td>876</td>
<td>5.5</td>
<td>3.4</td>
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CONCLUSIONS AND RECOMMENDATIONS

A number of energy-efficiency indices currently in use have been described and compared to the Home Heating Index. The HHI outperforms all of them by remaining constant during the winter months and varying only when the structure of a building is changed; in particular, the HHI is not affected by different internal heat gains or different inside average temperatures. Many of the other indices consider only auxiliary heating requirements while ignoring internal heat gains, or they fail to take the efficiency of the heating system into account. The Solar Fraction indices place too much emphasis on solar heat input, causing them to vary a great deal from month to month.

Measurements of the energy-efficiencies of various houses and student apartments during the winter of 1984-85 have yielded some interesting results. The HHI of most homes can be determined to within about 10% when energy consumption is monitored for three days. A home with a large south-glazing area will take a longer monitoring period before its HHI is known accurately, simply because of the larger variations in solar heat input. Of the student apartments, University Village phase 2 are the most energy-efficient with an average HHF of 7.0 Btu/DD-ft² (1.7 W/C°-m²), while Hawthorn Court and Schilletter Village are the most energy-inefficient with HHFs of 9.1 Btu/DD-ft² (2.2 W/C°-m²) and 9.2 Btu/DD-ft² (2.2 W/C°-m²) respectively.

Since the houses and student apartments were monitored under widely
different weather conditions during the winter, it has been possible to study the effects of wind and insolation on the HHI. Tightly sealed buildings have a nearly constant HHI as wind speed increases, while buildings with a high air infiltration rate, such as Schilletter Village student apartments, are affected significantly. The HHI of houses with a large south-glazing area are affected the most by insolation, as one would expect.

Data in the literature listing building characteristics and weather information have been useful in determining the energy-efficiencies of a number of solar homes. Two of the more famous homes, the Kelbaugh house and Balcomb house, are both very energy-efficient with HHIs of 3.0 Btu/DD-ft² (0.71 W/°C-m²) and 2.9 Btu/DD-ft² (0.69 W/°C-m²). Most solar homes have been found to be energy-efficient, although there are a few that the owners thought were energy-efficient, based on the Solar Heating Fraction or some other index, which actually perform rather poorly.

Recommendations for further study are as follows:

1. Test equipment should be installed in a number of houses to monitor energy usage continuously, with the purpose of seeing how accurately the HHI can be determined. Additionally, sensors should be placed on the exteriors or these houses to measure wind velocity, insolation, outside temperature, etc. Perhaps the most important item is the efficiency of the heating system, and it should be measured carefully. The maximum HHI of a building could be determined by monitoring it only at night when there is no solar heat input.
2. Solar houses across the United States should be similarly monitored. In this way, the strengths and weaknesses of the various designs can be examined, and also the applicability of the HHI as an indicator of energy-efficiency in different climates will be tested.

3. A home should be installed with electric resistance heating, so that the total heat delivered to the interior will be known very accurately. Assuming no other sources of heat and an even inside temperature, this method would provide the most accurate means of measuring the HHI.

4. Further work is recommended to compare actual HHI values with the values predicted from the construction drawings for a home. This will provide information about how good the standard energy calculation procedures are and how closely, from an energy point of view, homes are built to plan. A suggested source of data is a group of homes which have received Solar Bank subsidies from the Iowa Energy Policy Council, since all of them have had their HHI predicted; none of these have yet been through a whole heating season.
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ACKNOWLEDGMENTS

As I am not yet married I would like to dedicate this dissertation to my future wife, Mrs. Huebner, whomever she may be. I am grateful for the support and guidance of my advisor, Dr. Hodges, and also to Dr. Leacock for his encouragement in helping me prepare for the Qualifier Exam. I would like to thank my parents for providing a haven of refuge where I could rest and heal my wounds between battles. My thanks to the city of Ames which has remarkably few diversions, thus guaranteeing persistence in my studies. I will always be indebted to the dining hall, which has never poisoned me, at least not seriously. The music enthusiast next door to me in Buchanan Hall will not be forgotten for his teaching me the lyrics to "New York, New York" by playing the tune every night immediately after I had fallen into a blissful sleep. I would surely like to repay the debt by fixing his stereo, even if it is not broken. Unquestionably, I would not have made it through graduate school without my friends and colleagues, who never sabotaged my progress toward a Ph.D., and enabled me to laugh at those individuals who did. And finally, to the person who recommended Iowa State University to me; you can run but you cannot hide.
APPENDIX: HHI COMPUTER PROGRAM

10 CLS
20 PRINT "This program calculates the Home Heating Index, the Home Heating Requirement, auxiliary heat needed for October thru April, and the building heat loss coefficient based on the volume, floor area, R-values, etc. of a structure."
30 'This program was written by Jonathan Huebner as part of a Ph.D. thesis in physics under the direction of Dr. Laurent Hodges at Iowa State University.
40 PRINT:PRINT:PRINT "DO YOU WANT TO USE LATITUDE AND WEATHER DATA FOR AMES, IA? (Y,N)"
50 PRINT "(Otherwise, you will be asked to provide these data for your location.)"
60 A$=INKEY$: IF A$="" THEN 60
70 IF A$="Y" GOTO 810
80 IF A$="y" GOTO 810
90 PRINT:PRINT "ENTER LATITUDE"
100 PRINT:INPUT LAT
110 PRINT:PRINT "LATITUDE =";LAT;"DEGREES"
120 'WEATHER DATA FOR LOCATIONS OTHER THAN AMES, IOWA CAN BE ENTERED IN LINES 130 THRU 790.
130 PRINT:PRINT "ENTER MONTHLY DEGREE-DAYS FOR OCTOBER"
140 PRINT:INPUT MDD(1)
150 PRINT:PRINT "ENTER MONTHLY DEGREE-DAYS FOR NOVEMBER"
160 PRINT:INPUT MDD(2)
170 PRINT:PRINT "ENTER MONTHLY DEGREE-DAYS FOR DECEMBER"
180 PRINT:INPUT MDD(3)
190 PRINT:PRINT "ENTER MONTHLY DEGREE-DAYS FOR JANUARY"
200 PRINT:INPUT MDD(4)
210 PRINT:PRINT "ENTER MONTHLY DEGREE-DAYS FOR FEBRUARY"
220 PRINT:INPUT MDD(5)
230 PRINT:PRINT "ENTER MONTHLY DEGREE-DAYS FOR MARCH"
240 PRINT:INPUT MDD(6)
250 PRINT:PRINT "ENTER MONTHLY DEGREE-DAYS FOR APRIL"
260 PRINT:INPUT MDD(7)
270 CLS
280 PRINT "MONTHLY DEGREE-DAYS FOR OCTOBER =";MDD(1)
290 PRINT "MONTHLY DEGREE-DAYS FOR NOVEMBER =";MDD(2)
300 PRINT "MONTHLY DEGREE-DAYS FOR DECEMBER =";MDD(3)
310 PRINT "MONTHLY DEGREE-DAYS FOR JANUARY =";MDD(4)
320 PRINT "MONTHLY DEGREE-DAYS FOR FEBRUARY =";MDD(5)
330 PRINT "MONTHLY DEGREE-DAYS FOR MARCH =";MDD(6)
340 PRINT "MONTHLY DEGREE-DAYS FOR APRIL =";MDD(7)
350 PRINT:PRINT "ENTER AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR OCTOBER (BTU/SQ.FT.)"
360 PRINT:INPUT H(1)
370 PRINT:PRINT "ENTER AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR
NOVEMBER (BTU/SQ.FT.)"
380 PRINT:INPUT H(2)
390 PRINT:PRINT "ENTER AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR
DECEMBER (BTU/SQ.FT.)"
400 PRINT:INPUT H(3)
410 PRINT:PRINT "ENTER AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR
JANUARY (BTU/SQ.FT.)"
420 PRINT:INPUT H(4)
430 PRINT:PRINT "ENTER AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR
FEBRUARY (BTU/SQ.FT.)"
440 PRINT:INPUT H(5)
450 PRINT:PRINT "ENTER AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR
MARCH (BTU/SQ.FT.)"
460 PRINT:INPUT H(6)
470 PRINT:PRINT "ENTER AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR
APRIL (BTU/SQ.FT.)"
480 PRINT:INPUT H(7)
490 CLS
500 PRINT "AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR OCTOBER
=",H(1);"BTU/SQ.FT."
510 PRINT "AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR NOVEMBER
=",H(2);"BTU/SQ.FT."
520 PRINT "AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR DECEMBER
=",H(3);"BTU/SQ.FT."
530 PRINT "AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR JANUARY
=",H(4);"BTU/SQ.FT."
540 PRINT "AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR FEBRUARY
=",H(5);"BTU/SQ.FT."
550 PRINT "AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR MARCH
=",H(6);"BTU/SQ.FT."
560 PRINT "AVERAGE TOTAL DAILY HORIZONTAL INSOLATION FOR APRIL
=",H(7);"BTU/SQ.FT."
570 PRINT:PRINT "REFLECTANCE = 0.7 IF THE GROUND IS COMPLETELY COVERED
BY SNOW AND 0.2 IF THERE IS NO SNOW."
580 PRINT:PRINT "ENTER AVERAGE GROUND REFLECTANCE FOR OCTOBER"
590 PRINT:INPUT REF(1)
600 PRINT:PRINT "ENTER AVERAGE GROUND REFLECTANCE FOR NOVEMBER"
610 PRINT:INPUT REF(2)
620 PRINT:PRINT "ENTER AVERAGE GROUND REFLECTANCE FOR DECEMBER"
630 PRINT:INPUT REF(3)
640 PRINT:PRINT "ENTER AVERAGE GROUND REFLECTANCE FOR JANUARY"
650 PRINT:INPUT REF(4)
660 PRINT:PRINT "ENTER AVERAGE GROUND REFLECTANCE FOR FEBRUARY"
670 PRINT:INPUT REF(5)
680 PRINT:PRINT "ENTER AVERAGE GROUND REFLECTANCE FOR MARCH"
690 PRINT:INPUT REF(6)
700 PRINT:PRINT "ENTER AVERAGE GROUND REFLECTANCE FOR APRIL"
710 PRINT:INPUT REF(7)
720 CLS
730 PRINT "AVERAGE GROUND REFLECTANCE FOR OCTOBER =";REFL(1)
740 PRINT "AVERAGE GROUND REFLECTANCE FOR NOVEMBER =";REFL(2)
750 PRINT "AVERAGE GROUND REFLECTANCE FOR DECEMBER =";REFL(3)
760 PRINT "AVERAGE GROUND REFLECTANCE FOR JANUARY =";REFL(4)
770 PRINT "AVERAGE GROUND REFLECTANCE FOR FEBRUARY =";REFL(5)
780 PRINT "AVERAGE GROUND REFLECTANCE FOR MARCH =";REFL(6)
790 PRINT "AVERAGE GROUND REFLECTANCE FOR APRIL =";REFL(7)
800 PRINT:GOTO 1040
810 LAT=42
820 'WEATHER CONDITIONS FOR AMES, IOWA ARE LISTED IN LINES 830 THRU 1030. MDD IS THE MONTHLY DEGREE-DAYS, H IS THE DAILY HORIZONTAL INSOLATION, AND REFL IS THE GROUND REFLECTANCE.
830 MDD(1)=384
840 MDD(2)=849
850 MDD(3)=1237
860 MDD(4)=1395
870 MDD(5)=1151
880 MDD(6)=955
890 MDD(7)=477
900 H(1)=987
910 H(2)=604
920 H(3)=501
930 H(4)=637
940 H(5)=900
950 H(6)=1211
960 H(7)=1419
970 REFL(1)=.2
980 REFL(2)=.25
990 REFL(3)=.4
1000 REFL(4)=.5
1010 REFL(5)=.45
1020 REFL(6)=.35
1030 REFL(7)=.2
1040 PRINT:PRINT "DO YOU WANT AN EXAMPLE OF THE PARAMETERS ASKED FOR BY THIS PROGRAM? (Y,N)"
1050 A$=INKEY$:IF A$="" THEN 1050
1050 PRINT:IF A$="N" GOTO 1130
1070 IF A$="n" GOTO 1130
1080 CLS
1090 PRINT "THE TILT ANGLE OF A SURFACE IS 90 DEGREES IF IT IS VERTICAL AND ZERO IF IT IS HORIZONTAL."
1100 PRINT "THE AZIMUTHAL ANGLE OF A SURFACE IS ZERO IF IT FACES SOUTH, WEST = 90 DEGREES, NORTH = 180 DEGREES, AND EAST = 90 DEGREES."
1110 PRINT "THE TRANSMISSION COEFFICIENT OF A SINGLE-PANE WINDOW IS TYPICALLY .8, DOUBLE-PANE IS .7, AND TRIPLE-PANE IS .6"
1120 PRINT "THE R-VALUE OF A SINGLE-PANE WINDOW IS TYPICALLY .9, DOUBLE-PANE IS 1.8, AND TRIPLE-PANE IS 2.7"
1130 PRINT:PRINT "IS NIGHT INSULATION USED ON WINDOWS? (Y,N)"
1140 A$=INKEY$:IF A$="" THEN 1140
94

1150 PRINT: IF A$="Y" THEN PRINT "ENTER R-VALUE OF NIGHT INSULATION (COMMA) HOURS PER DAY IT IS USED": PRINT "": INPUT RVNI, HPD
1160 IF A$="Y" THEN PRINT "ENTER R-VALUE OF NIGHT INSULATION (COMMA) HOURS PER DAY IT IS USED": PRINT "": INPUT RVNI, HPD
1170 IF A$="Y" THEN PRINT "R-VALUE OF NIGHT INSULATION ="; RVNI; PRINT "HOURS PER DAY ="; HPD
1180 IF A$="Y" THEN PRINT "R-VALUE OF NIGHT INSULATION ="; RVNI; PRINT "HOURS PER DAY ="; HPD
1190 IF RVNI>9 THEN RVNI=9
1200 PRINT: PRINT "DOES THE BUILDING CONTAIN A DIRECT GAIN SYSTEM? (Y,N)"
1210 DG$=INKEY$: IF DG$ = " " THEN 1210
1220 PRINT: IF DG$="Y" THEN AVERAGE=1
1230 IF DG$="y" THEN AVERAGE=1
1240 PRINT "DOES THE BUILDING CONTAIN A MASONRY THERMAL STORAGE WALL SYSTEM? (Y,N)"
1250 MSW$=INKEY$: IF MSW$="" THEN 1250
1260 IF MSW$="Y" THEN AVERAGE=AVERAGE+1
1270 IF MSW$="y" THEN AVERAGE=AVERAGE+1
1280 PRINT: PRINT "DOES THE BUILDING CONTAIN A WATER THERMAL STORAGE WALL SYSTEM? (Y,N)"
1290 WSW$=INKEY$: IF WSW$="" THEN 1290
1300 IF WSW$="Y" THEN AVERAGE=AVERAGE+1
1310 IF WSW$="y" THEN AVERAGE=AVERAGE+1
1320 PRINT: PRINT "ENTER TILT ANGLE OF A WINDOW IN DEGREES (COMMA) AZIMUTHAL ANGLE IN DEGREES (COMMA) TRANSMISSION COEFFICIENT (COMMA) R-VALUE (COMMA) AREA OF WINDOW IN SQUARE FEET"
1330 PRINT "NOTE: IF A WATER WALL IS BEHIND A DOUBLE-PANE WINDOW, THEN ENTER 3.0 INSTEAD OF 1.8 FOR THE R-VALUE. IF A MASONRY WALL IS BEHIND A DOUBLE-PANE WINDOW, THEN ENTER 4.6 FOR THE R-VALUE."
1350 PRINT: PI=3.1415926535#
1360 LAT=PI*LAT/180
1370 INPUT TILT,GAMMA,TRANS,RV, AREA
1380 IF AREA=0 GOTO 2410
1390 AP=AP+AREA*SIN(TILT)
1400 PRINT: PRINT "TILT ANGLE ="; TILT; "DEGREES"
1410 PRINT "AZIMUTHAL ANGLE ="; GAMMA; "DEGREES"
1420 PRINT "TRANSMISSION COEFFICIENT ="; TRANS
1430 PRINT "R-VALUE ="; RV
1440 PRINT "AREA ="; AREA; "SQUARE FEET"
1450 'LINES 1460 THRU 1470 CALCULATE THE HEAT LOSS OF THE BUILDING'S WINDOWS.
1460 AHL=PI+AREA*(24-HPD)/RV+AREA*HPD/(RV+RVNI)
1470 PRINT: HLC=HLC+AREA*(24-HPD)/RV+AREA*HPD/(RV+RVNI)
1480 'LINES 1490 THRU 2380 CALCULATE THE SOLAR HEAT INPUT.
1490 D(1)=31
1500 D(2)=30
1510 D(3)=31
1520 D(4)=31
1530 D(5)=28
1540 D(6)=31
1550 D(7)=30
1560 D0Y(1)=288
1570 D0Y(2)=318
1580 D0Y(3)=344
1590 D0Y(4)=17
1600 D0Y(5)=47
1610 D0Y(6)=75
1620 D0Y(7)=105
1630 SC=429
1640 IF TILT=90 THEN TILT=89.999
1650 IF TILT=180 THEN TILT=179.99
1660 TILT=PI*TILT/180
1670 IF GAMMA=90 THEN GAMMA=89.99
1680 IF GAMMA=180 THEN GAMMA=179.99
1690 GAMMA=PI*GAMMA/180
1700 DEF FNARCSIN(X)=ATN(X/SQR(1-X*X))
1710 DEF FNARCCOS(X)=.5*PI-ATN(X/SQR(1-X*X))
1720 DEFINT J
1730 FOR J=1 TO 7
1740 SIND=.397949*SIN(2*PI*(D0Y(J)+284)/365)
1750 DECL=FNARCSIN(SIND)
1760 IF DECL=0 THEN DECL=.001
1770 COSD=COS(DECL)
1780 TAND=TAN(DECL)
1790 SINL=SIN(LAT)
1800 COSL=COS(LAT)
1810 TANL=TAN(LAT)
1820 OMS=FNARCCOS(-TANL*TAND)
1830 SINOMS=SIN(OMS)
1840 COSOMS=COS(OMS)
1850 HO=24*SC*(1+.033*COS(2*PI*D0Y(J)/365))*(COSL*COSD*SINOMS*SINL*SIND)/PI
1860 KT=H(J)/HO
1870 HDH=1.39-4.03*KT+5.53*KT*KT-3.11*KT+3
1880 SINT=SIN(TILT)
1890 COST=COS(TILT)
1900 TANT=TAN(TILT)
1910 IF TILT=0 THEN RB=1:GOTO 2320
1920 IF GAMMA=0 GOTO 1930 ELSE GOTO 1970
1930 OMS=FNARCCOS(-TAN(LAT-TILT)*TAND)
1940 IF OMS<OMS THEN OMS=OMS
1950 RB=(COS(LAT-TILT)*COSD*SIN(OMS)+OMS*SIN(LAT-TILT)*SIND)/(COSL*COSD*SINOMS*OMS*SIND*SINL)
1960 GOTO 2320
1970 SING=SIN(GAMMA)
1980 COSG=COS(GAMMA)
1990 TANG=TAN(GAMMA)
2000 A=COSL/(SING*TANT)+SINL/TANG
2010 B=TANL/(COSL/TANG-SINL/(SING*TANT))
96

2020 C=A*A-B*B+1
2030 AZI=FNARCSIN(COSD*SINDMS)
2040 IF COSOMS>0 GOTO 2060
2050 AZI=PI-AZI
2060 IF (AZI+GAMMA-3*PI/2)>0 GOTO 2080
2070 IF C>0 GOTO 2160 ELSE GOTO 2140
2080 IF (TILT+LAT-DECL-PI/2)>0 GOTO 2130
2090 OMSS=OMS
2100 OMSR=-OMS
2110 GOSUB 2360
2120 GOTO 2320
2130 IF C>0 GOTO 2240
2140 RB=0
2150 GOTO 2320
2170 IF Z>OMS THEN OMSR=-OMS ELSE OMSR=-Z
2180 IF (A-B)<0 GOTO 2190 ELSE GOTO 2200
2190 OMSR=-OMS
2210 IF Z>OMS THEN OMSS=OMS ELSE OMSS=Z
2220 GOSUB 2360
2230 GOTO 2320
2240 OMSR=-OMS
2260 GOSUB 2360
2270 RB1=RB
2290 OMSS=OMS
2300 GOSUB 2360
2310 RB=RB+RB1
2320 R=(1-HDH)*RB+HDH*(1+COST)/2+REFL(J)*(1-COST)/2
2330 HT=R*H(J)
2340 SHI(J)=SHI(J)+HT*AREA*D(J)*TRANS/10000000
2350 GOTO 2380
2360 RB=((COST*SIND*SINL-COSL*COST*SINT*COSG)*(OMSS-OMSR)+
(COSL*COST+COSG*SINT*SINL)*COSD*(SIN(OMSS)-SIN(OMSR))-
(COSD*SINT*SING)*(COS(OMSS)-COS(OMSR)))/
(2*(COSL*COSD*SINDMS+OMS*SINDMS))
2370 RETURN
2380 NEXT J
2390 PRINT "IF THERE ARE MORE WINDOWS THEN ENTER VALUES AS BEFORE, IF
NOT THEN ENTER ZEROS."
2400 PRINT:GOTO 1370
2410 PRINT:PRINT "ENTER TOTAL FLOOR AREA OF HOUSE IN SQUARE FEET"
2420 PRINT:INPUT FLOOR
2430 PRINT:PRINT "TOTAL FLOOR AREA =";FLOOR ;"SQUARE FEET"
2440 PRINT:PRINT "NONWINDOW AREAS INCLUDE WALLS, DOORS, CEILING, ETC.
BUT DO NOT INCLUDE BASEMENT WALL AREAS THAT ARE MORE THAN 3 FEET
UNDERGROUND."
2450 PRINT:PRINT "ENTER A NONWINDOW AREA IN SQUARE FEET(COMMA)R-VALUE"
2460 PRINT:INPUT AREA,RV
2470 PRINT:IF AREA=0 GOTO 2540
2480 PRINT "AREA =";AREA;" SQUARE FEET"
2490 PRINT "R-VALUE =";RV
2500 'LINES 2510 THRU 2600 CALCULATE THE HEAT LOSS OF WALLS, CEILING, ETC.
2510 PRINT:HLC=HLC+AREA*24/RV
2520 PRINT "IF THERE ARE MORE NONWINDOW AREAS THEN ENTER VALUES AS BEFORE, IF NOT THEN ENTERZEROES"
2530 PRINT:GOTO 2460
2540 PRINT "ENTER VOLUME OF AIR IN HOUSE THAT IS KEPT AT 50 DEGREES FAHRENHEIT OR ABOVE (CUBIC FEET)"
2550 PRINT:INPUT VOL
2560 PRINT:PRINT "VOLUME =";VOL;" CUBIC FEET"
2570 PRINT:PRINT "ENTER NUMBER OF AIR CHANGES PER HOUR"
2580 PRINT:INPUT ACPH
2590 PRINT:PRINT "AIR CHANGES PER HOUR =";ACPH
2600 PRINT:PRINT:HLC=HLC+.018*ACPH*VOL*24
2610 IF DG$="N" GOTO 3000
2620 IF DG$="n" GOTO 3000
2630 'LINES 2640 THRU 2990 CALCULATE THE MONTHLY HEATING NEEDS FOR A DIRECT GAIN SYSTEM.
2640 PRINT:"ENTER THE NUMBER OF ONE OF THE FOLLOWING NINE SYSTEMS WHICH MOST CLOSELY APPROXIMATES THE BUILDING'S DIRECT GAIN SYSTEM."
2650 PRINT:"THERMAL"
2660 PRINT:"STORAGE"
2670 PRINT:"GLAZING- NO. OF NIGHT"
2680 PRINT:"SYSTEM AREA RATIO GLAZINGS INSULATION (BTU/SQ.FT.-DEG.F) (IN.)"
2690 PRINT

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<td>5</td>
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<td>6</td>
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<td>YES</td>
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<tr>
<td>7</td>
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4"
2770 PRINT " 8  6  3  NO  60 4"
2780 PRINT " 9  2  YES  60 4"
2790 SYS$=INKEY$:IF SYS$="" THEN 2790
2800 IF SYS$="1" THEN A=.565:B=1.009:C=1.044:D1=.7175:R=.3931:G=9.359999
2810 IF SYS$="2" THEN A=.5906:B=1.006:C=1.065:D1=.8099:R=.4681:G=5.28
2820 IF SYS$="3" THEN A=.5442:B=.9715:C=1.13:D1=.9273:R=.7086:G=2.64
2830 IF SYS$="4" THEN A=.5739:B=.9948:C=1.251:D1=.061:R=.7905:G=9.600001
2840 IF SYS$="5" THEN A=.618:B=1.006:C=1.276:D1=.156:R=.7528:G=5.52
2850 IF SYS$="6" THEN A=.5601:B=.9839:C=1.352:D1=.151:R=.8879:G=2.38
2870 IF SYS$="8" THEN A=.6763:B=.9994:C=1.4:D1=.394:R=.7604:G=5.28
2880 IF SYS$="9" THEN A=.6182:B=.9859:C=1.566:D1=.437:R=.899:G=2.4
2890 F=(HLC-AHLC)/HLC
2900 FOR J=1 TO 7
2910 GHLC(J)=MDD(J)*HLC/1000000!
2920 SLR(J)=SHI(J)/GHL(J)
2930 FRACT=SLR(J)/(F+G/HLC)
2940 IF FRACT>R THEN SHF(J)=1-F*(1-B+C*EXP(-01*SLR(J)/(1-F+G/HLC)))*(1+G*AP/HLC))
2950 IF FRACT<R THEN SHF(J)=1-F*(1-A*SLR(J)/(F+G/HLC)))*(1+G*AP/HLC)
2960 IF SHF(J)>1 THEN SHF(J)=1
2970 USH(J)=SHF(J)*GHL(J)
2980 MHN(J)=GHL(J)-USH(J)
2990 NEXT J
3000 IF MSW$="N" GOTO 3140
3010 IF MSW$="n" GOTO 3140
3020 "LINES 3030 THRU 3130 CALCULATE THE MONTHLY HEATING NEEDS FOR A
3030 FOR J=1 TO 7
3040 GHLC(J)=MDD(J)*HLC/1000000!
3050 SLR(J)=SHI(J)/GHL(J)
3060 IF SLR(J)<.1 THEN SHF(J)=.452*SLR(J) ELSE SHF(J)=1.0137-1.0392*EXP(-.7047*SLR(J))
3070 IF SLR(J)<.5 THEN SHFNI(J)=.7197*SLR(J) ELSE SHFNI(J)=1.0074-1.1195*EXP(-1.0948*SLR(J))
3080 IF SHF(J)>1 THEN SHF(J)=1
3090 IF SHFNI(J)>1 THEN SHFNI(J)=1
3100 SHF(J)=(SHFNI(J)-SHF(J))*RVNI/9+SHF(J)
3110 USH(J)=SHF(J)*GHL(J)
3120 MHN(J)=MHN(J)+GHLC(J)-USH(J)
3130 NEXT J
3140 IF WSW$="N" GOTO 3290
3150 IF WSW$="n" GOTO 3290
3160 "LINES 3170 THRU 3270 CALCULATE THE MONTHLY HEATING NEEDS FOR A
3170 FOR J=1 TO 7
3180 GHL(J)=MDD(J)*HLC/1000000!
3190 SLR(J)=SHI(J)/GHL(J)
3200 IF SLR(J)<.8 THEN SHF(J)=.5995*SLR(J) ELSE SHF(J)=1.0149-1.26+EXP(-1.0701*SLR(J))
3210 IF SLR(J)<.7 THEN SHFNI(J)=.7642*SLR(J) ELSE SHFNI(J)=1.0102-1.4027*EXP(-1.5461*SLR(J))
3220 IF SHF(J)>1 THEN SHF(J)=1
3230 IF SHFNI(J)>1 THEN SHFNI(J)=1
3240 USH(J)=SHF(J)*GHL(J)
3250 MHN(J)=MHN(J)+GHL(J)-USH(J)
3260 NEXT J
3270 'LINES 3290 THRU 3340 CALCULATE MONTHLY HEATING NEEDS, ANNUAL HEATING NEEDS, HOME HEATING REQUIREMENT, AND HOME HEATING INDEX.
3290 FOR J=1 TO 7
3300 MHN(J)=MHN(J)/AVERAGE
3310 AHN=AHN+MHN(J)
3320 NEXT J
3330 HHR=(MHN(3)+MHN(4)+MHN(5))*1000000!/(MDD(3)+MDD(4)+MDD(5))
3340 HHI=HHR/FLOOR
3350 HLC=INT(HLC)
3360 AHN=INT(100*AHN)/100
3370 HHR=INT(HHR)
3380 HHI=INT(100*HHI)/100
3390 FOR J=1 TO 7
3400 GHL(J)=INT(100*GHL(J))/100
3410 SHI(J)=INT(100*SHI(J))/100
3420 SLR(J)=INT(100*SLR(J))/1000
3430 SHF(J)=INT(1000*SHF(J))/1000
3440 USH(J)=INT(100*USH(J))/100
3450 MHN(J)=INT(100*MHN(J))/100
3460 NEXT J
3470 'THE REMAINDER OF THIS PROGRAM DISPLAYS RESULTS.
3480 PRINT TAB(21); "OCT. NOV. DEC. JAN. FEB. MAR. APR."
3490 PRINT "1. Total monthly"
3500 PRINT "##.##";MDD(1);:PRINT USING "##.##";MDD(2);:PRINT USING "##.##";MDD(3);
3510 PRINT TAB(39);:PRINT USING "##.##";MDD(4);
3520 PRINT TAB(57);:PRINT USING "##.##";MDD(5);
3530 PRINT TAB(75);:PRINT USING "##.##";MDD(7)
3540 PRINT "2. Gross heat"
3550 PRINT "##.##";GHL(1);:PRINT USING "##.##";GHL(2);
3560 PRINT TAB(38);:PRINT USING "##.##";GHL(3);
3570 PRINT TAB(47);:PRINT USING "##.##";GHL(4);
3580 PRINT TAB(56);:PRINT USING "##.##";GHL(5);
3590 PRINT TAB(65);:PRINT USING "##.##";GHL(6);
3600 PRINT TAB(74);:PRINT USING "##.##";GHL(7)
3550 PRINT "3. Solar heat"
3560 PRINT " input (MBTU)"; PRINT TAB(20); PRINT USING "##.##"; SHI(1); PRINT TAB(29); PRINT USING "##.##"; SHI(2); PRINT TAB(38); PRINT USING "##.##"; SHI(3);  
3570 PRINT TAB(47); PRINT USING "##.##"; SHI(4); PRINT TAB(56); PRINT USING "##.##"; SHI(5); PRINT TAB(65); PRINT USING "##.##"; SHI(6); PRINT TAB(74); PRINT USING "##.##"; SHI(7)
3580 PRINT "4. Solar load"
3590 PRINT " ratio"; PRINT TAB(20); PRINT USING "#.###"; SLR(1); PRINT TAB(29); PRINT USING "#.###"; SLR(2); PRINT TAB(38); PRINT USING "#.###"; SLR(3);  
3600 PRINT TAB(47); PRINT USING "#.###"; SLR(4); PRINT TAB(56); PRINT USING "#.###"; SLR(5); PRINT TAB(65); PRINT USING "#.###"; SLR(6); PRINT TAB(74); PRINT USING "#.###"; SLR(7)
3610 PRINT "5. Solar heating"
3620 PRINT " fraction"; PRINT TAB(20); PRINT USING "#.###"; SHF(1); PRINT TAB(29); PRINT USING "#.###"; SHF(2); PRINT TAB(38); PRINT USING "#.###"; SHF(3);  
3630 PRINT TAB(47); PRINT USING "#.###"; SHF(4); PRINT TAB(56); PRINT USING "#.###"; SHF(5); PRINT TAB(65); PRINT USING "#.###"; SHF(6); PRINT TAB(74); PRINT USING "#.###"; SHF(7)
3640 PRINT "6. Useful solar"
3650 PRINT " heat (MBTU)"; PRINT TAB(20); PRINT USING "##.##"; USH(1); PRINT TAB(29); PRINT USING "##.##"; USH(2); PRINT TAB(38); PRINT USING "##.##"; USH(3);  
3660 PRINT TAB(47); PRINT USING "##.##"; USH(4); PRINT TAB(56); PRINT USING "##.##"; USH(5); PRINT TAB(65); PRINT USING "##.##"; USH(6); PRINT TAB(74); PRINT USING "##.##"; USH(7)
3670 PRINT "7. Auxiliary heat"
3680 PRINT " needed (MBTU)"; PRINT TAB(20); PRINT USING "##.##"; MHN(1); PRINT TAB(29); PRINT USING "##.##"; MHN(2); PRINT TAB(38); PRINT USING "##.##"; MHN(3);  
3690 PRINT TAB(47); PRINT USING "##.##"; MHN(4); PRINT TAB(56); PRINT USING "##.##"; MHN(5); PRINT TAB(65); PRINT USING "##.##"; MHN(6); PRINT TAB(74); PRINT USING "##.##"; MHN(7)
3700 PRINT PRINT PRINT "BUILDING HEAT LOSS COEFFICIENT ="; HLC; "BTU/DEGREE-DAY"
3710 PRINT "AUXILIARY HEAT NEEDED FOR OCTOBER THRU APRIL ="; AHN; "MBTU"
3720 PRINT "HOME HEATING REQUIREMENT ="; HHR; "BTU/DEGREE-DAY"
3730 PRINT "HOME HEATING INDEX ="; HHI; "BTU/DEGREE-DAY-SQ.FT."; PRINT ""
3740 PRINT "DO YOU WANT THE ABOVE RESULTS PRINTED OUT? (Y,N)"
3750 PR$=INKEY$; IF PR$="" THEN 3750
3760 IF PR$="Y" THEN 3790
3770 IF PR$="y" THEN 3790
3780 GOTO 4050
3790 LPRINT TAB(21); "OCT. NOV. DEC. JAN. FEB. MAR. APR."
3800 LPRINT LPRINT "1. Total monthly"
BUILDING HEAT LOSS COEFFICIENT = HLC BTU/DEGREE-DAY
4020 LPRINT: LPRINT "AUXILIARY HEAT NEEDED FOR OCTOBER THRU APRIL ="; AHN; "MBTU"
4030 LPRINT: LPRINT "HOME HEATING REQUIREMENT ="; HHR; "BTU/DEGREE-DAY"
4040 LPRINT: LPRINT "HOME HEATING INDEX ="; HHI; "BTU/DEGREE-DAY-SQ.FT."
4050 PRINT: PRINT "DO YOU WANT TO CALCULATE THE HHI OF ANOTHER BUILDING? (Y,N)"
4060 AB$=INKEY$: IF AB$="" THEN 4060
4070 IF AB$="Y" THEN RUN
4080 IF AB$="y" THEN RUN
4090 END